

**RESEARCH AND DEVELOPMENT OF THE VORTEX VALVE
PRINCIPLE AND ITS APPLICATION TO A HOT GAS
(5500°F) SECONDARY INJECTION THRUST
VECTOR CONTROL SYSTEM**

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SECTION 1

INTRODUCTION

This program is the study of a vortex valve controlled secondary injection thrust vector control system, operating with highly aluminized gas from a solid propellant gas generator (SPGG). Various performance characteristics will be determined, including static and dynamic system performance and the ability of the vortex valve to handle the aluminized hot gas. The application of this technique for thrust vector control of a solid propellant rocket engine, using direct engine bleed, will be considered.

SECTION 2

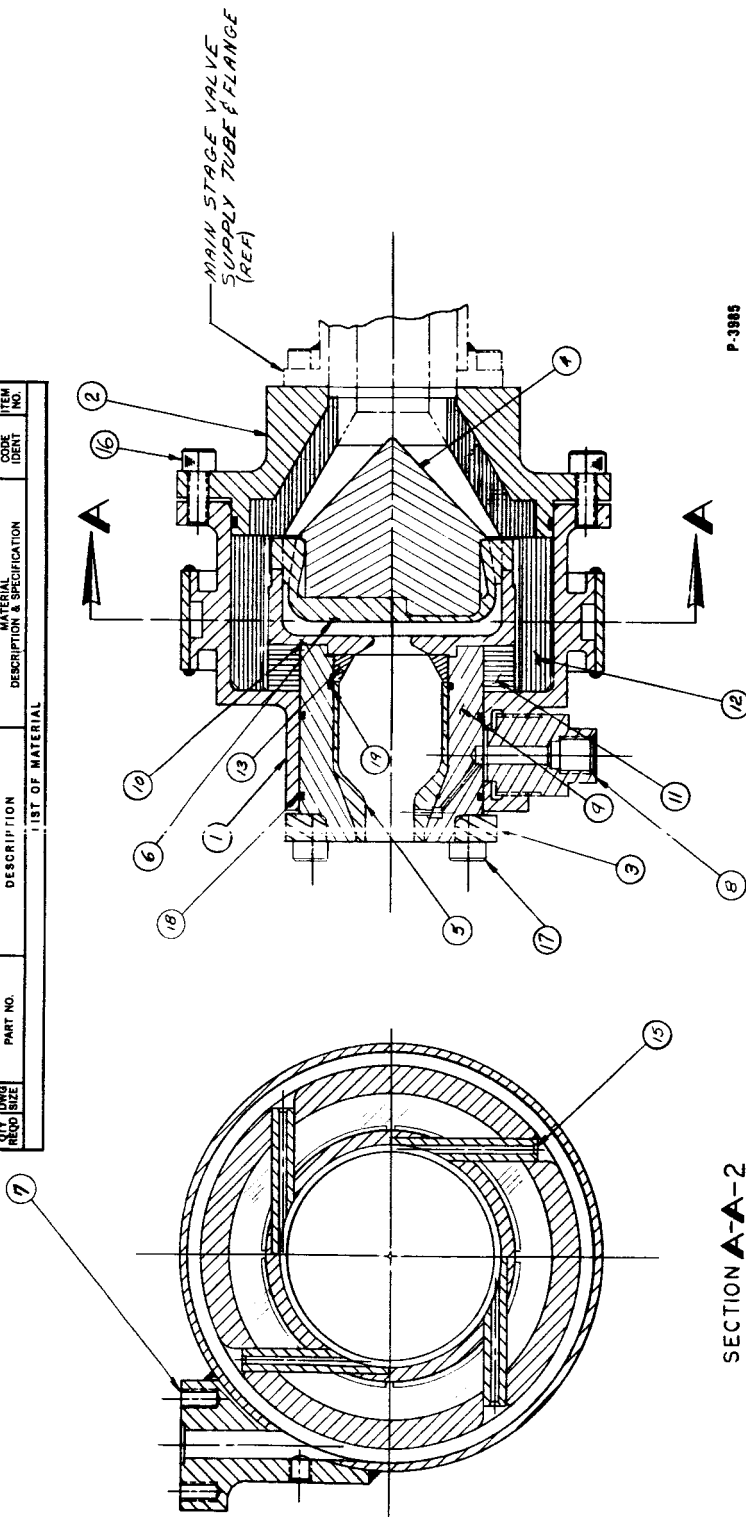
ACCOMPLISHMENTS THIS PERIOD

A single vortex valve SITVC system, designated System Test Number 2, was cold and hot gas tested this period. The phenolic insulation withstood exposure to the 5500°F gas with minimum erosion. The fabrication and layup techniques established for the insulation appear adequate for this application. The major accomplishment of this test was the elimination of the aluminum oxide build-up in the vortex valve. This was accomplished by a redesign of the system to minimize the tungsten mass, to provide uniform gas velocity in the system and to minimize the gas heat loss.

The test accomplishments were limited because the 2000°F SPGG failed to ignite. It was agreed between NASA-Langley and Bendix project personnel that the same type of test should be conducted before testing the planned two-valve system arrangement programmed for Test Number 3. Therefore, Test Number 3 will be the same system arrangement with the required design changes made before the test is conducted. The method in which Test Firing Number 2 was conducted and a summary of the results are given in detail in Appendix A, and a revised test procedure for Test Number 3 is presented in Appendix B. The new procedure has incorporated new programming and safety check points, including a 5500°F SPGG abort switch. This will increase the test reliability.

Hot gas Test Number 2 pointed out marginal design areas where redesign will be required prior to hot gas Test Number 3. One of the more critical areas is the vortex power valve. The tungsten button cap will be replaced with carbon-silica phenolic, and the plenum chamber insulation and liner have been redesigned to a one-piece construction. Elastomer seals are added to provide a positive seal between the valve body and insulation and the tungsten liner. The seal location and valve redesign are shown in Figure 1. Note the location of the tungsten liner seal. Any outgassing of the seal will bleed into the plenum chamber, thus preventing implosion due to gas buildup behind the liner.

QTY	DWG	REQD	SIZE	PART NO.	DESCRIPTION	MATERIAL	DESCRIPTION & SPECIFICATION	CODE	ITEM
1	1	1	1	1	1	1	1	1	1
1	STOCK	0" RING MARKER	SIZE #2-29-V397-9						19
2	STOCK	0" RING MARKER	SIZE #2-36-V399-9						18
4	STOCK	SCR 500.10 CAP	.312-24UNF-3AX.6210						17
6	STOCK	SCR 500.10 CAP	.312-24UNF-3AX.7510						16
4	8	2159113	INJECTOR						15
1	8	2162241	SUPPORT RING						14
1	8	2162241	VALVE BODY INSULATOR						13
1	8	2162241	VALVE BODY INSULATOR						12
1	8	2161355-1	VORTEX CHAMBER						11
1	8	2162502	INSULATING CHAMBER						10
1	8	2162502	INSULATING CHAMBER						9
1	8	2162502	INSULATING CHAMBER						8
1	8	2159099	VALVE PORT RING ASSY						7
1	8	2161187	BUTTON VALVE						6
1	8	2162209	ORIFICE VALVE PLENUM CHAMBER OUTLET						5
1	8	2162242	BUTTON CAP VORTEX VALVE						4
1	8	2161558	EXHAUST FLANGE VALVE						3
1	8	2161187	END CAP VALVE ASSY						2
1	8	2161185-1	VALVE BODY						1



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SECTION A-A-2

Figure 1 - 5500°f Vortex Valve Assembly

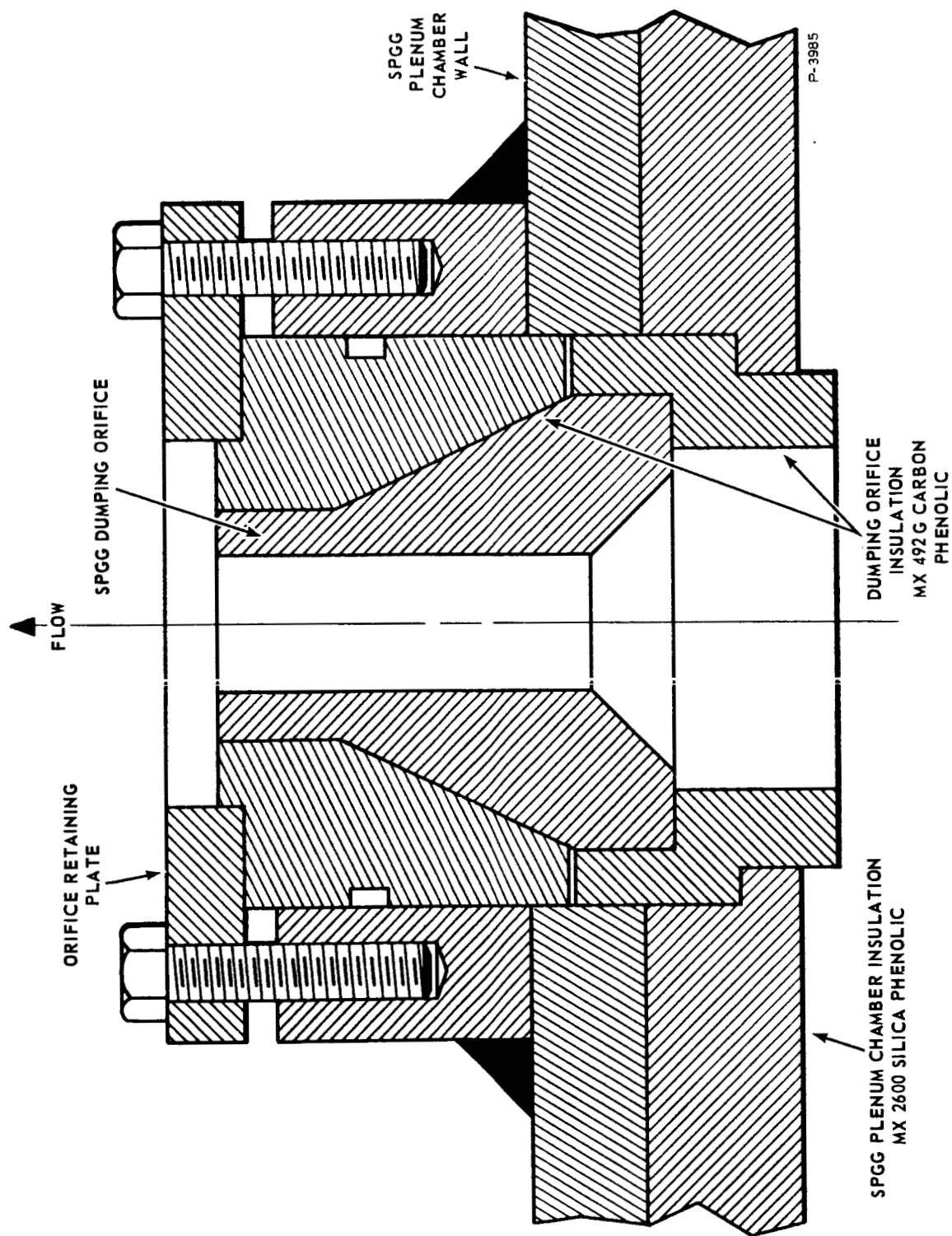


Figure 2 - 5500°F SPGG Dumping Orifice

The dumping orifice in the SPGG plenum chamber has been redesigned to provide a larger load bearing area and more insulation between the orifice and the retaining wall. Figure 2 is a layout drawing of the redesign showing the dumping orifice and other areas where minor design changes were incorporated.

Procurement of the tungsten and insulation is in process for Test Firing Number 3. Orders were placed for adequate material to cover Test Firings 3 and 4. However, a hold was placed on the tungsten finished parts for Firing Test Number 4, anticipating a design change. Because of the long lead time in procurement of the raw stock, it seems practical to order the raw stock but delay machining the parts. This procedure would offer some cost advantage in quantity buying of stock without having excess parts on hand.

SECTION 3
PROBLEM AREAS

There are no major technical problem areas this period. Refurbishment and rework have started, anticipating scheduled delivery of raw stock.

SECTION 4
MEETINGS AND CONTACTS

Mr. G. L. Smith of NASA-Langley visited Bendix for a general review of the SITVC development program. The test schedule and program cost were discussed. Mr. Smith also witnessed Test Firing Number 2 during his visit.

SECTION 5
PLANS FOR NEXT PERIOD

The following tasks will be completed during the next reporting period, which ends 2 July 1966:

- (1) A single vortex valve circuit will be set up and tested with 2000°F gas in the pilot stage and 5500°F in the power stage.
- (2) A simulated single-axis SITVC system will be set up and tested for steady-state performance on cold gas.
- (3) The test effort will be reviewed with respect to the next scheduled hot gas test.

SECTION 6

PROGRAM SCHEDULE

The existing program plan is shown in Figure 3 and indicates the various subtasks and the planned period of accomplishment.

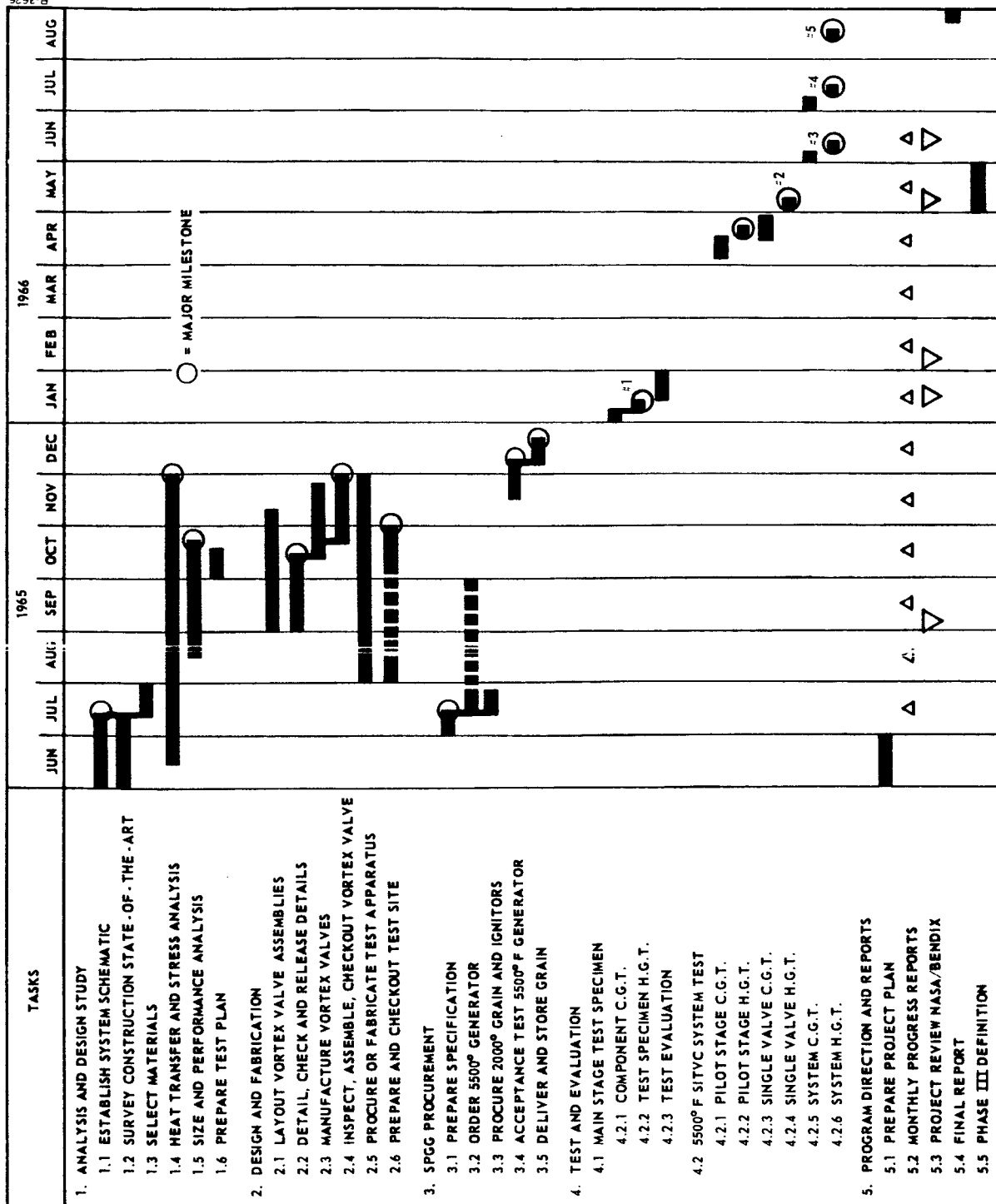


Figure 3 - Program Schedule

SECTION 7
MONTHLY FINANCIAL AND MANPOWER
UTILIZATION REPORT

The cumulative manhour expenditures by category through May 31 are as follows:

Engineering	5003
Drafting	337
Technician	1984
Miscellaneous	802
Shop	1322

A graphic and tabular presentation of contract expenditures is shown in Figure 4.

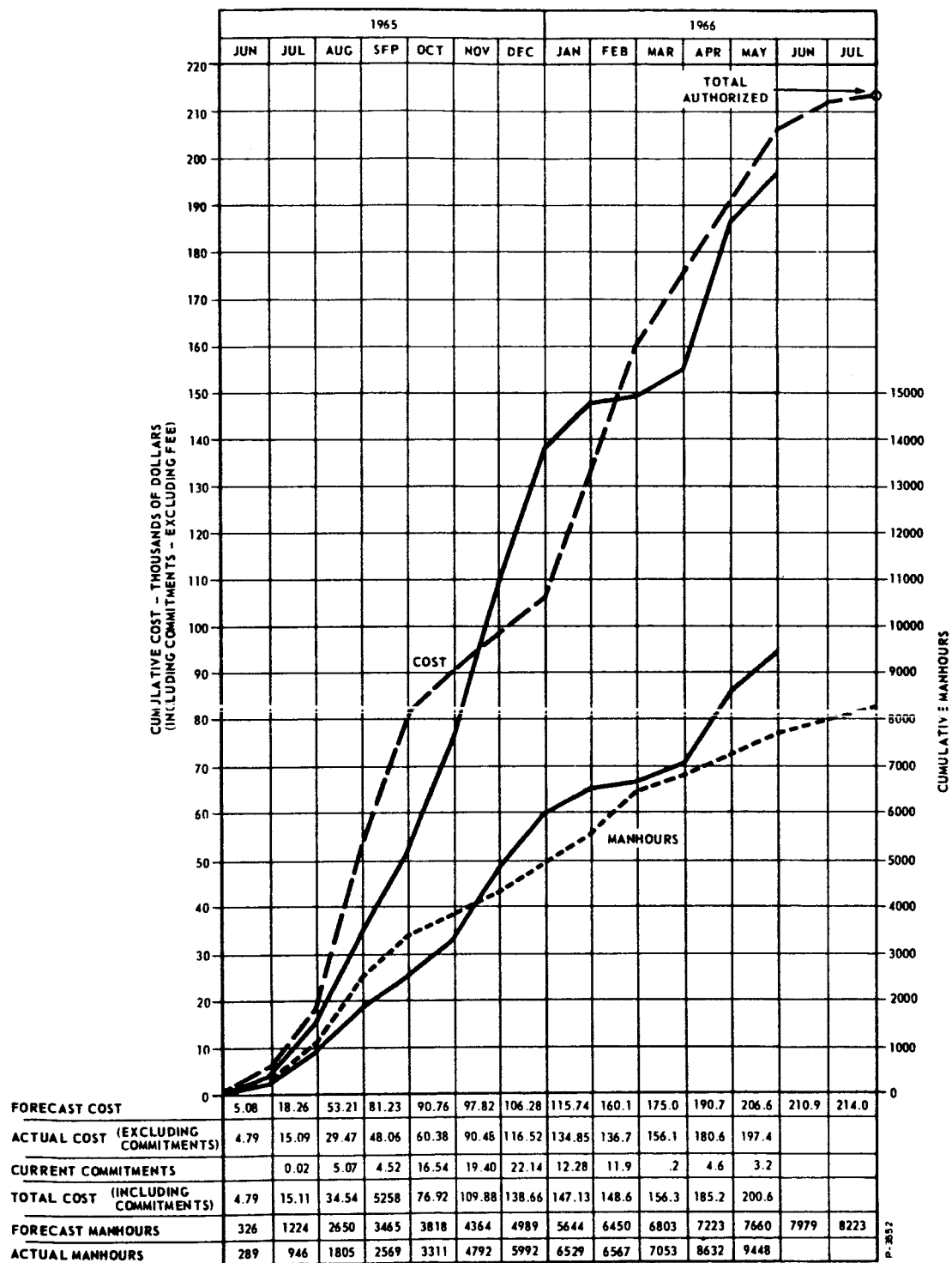


Figure 4 - Research and Development of the Vortex Valve Principle and its Application to a Hot-Gas (5500°F) Secondary Injection Thrust Vector Control System

APPENDIX A

RESULTS OF 5500°F SITVC SYSTEM - SINGLE VORTEX VALVE
TEST NUMBER 2

APPENDIX A

RESULTS OF 5500°F SITVC SYSTEM - SINGLE VORTEX VALVE TEST NUMBER 2

The system tested was a single vortex valve 5500°F SITVC System with a 2000°F control stage. The test objectives were to verify the structural integrity of the vortex valve design and its ability to modulate 5500°F aluminized gas using 2000°F nonaluminized gas for control.

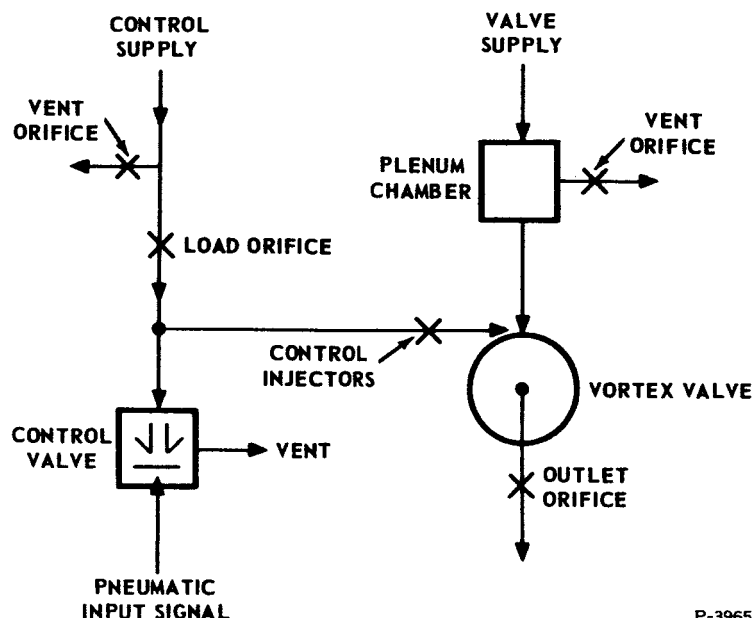
The test was conducted in two parts. The first part of the test was a steady-state cold gas test of the system and its individual components using nitrogen as the gas source. The second part of the test was a steady-state hot gas test of the system with a 5500°F SPGG used as the hot gas supply and a 2000°F SPGG used as the hot gas control source.

The cold gas test of the single vortex valve system and its components produced the desired performance. All of the objectives of the hot gas tests were not met, due to a misfire of the 2000°F SPGG. The test results obtained with only the 5500°F SPGG in operation provided a good evaluation of the vortex valve design. The test revealed that the new valve design will remain free of aluminum deposits in critical areas. However, minor design modifications are required to compensate for the vortex chamber thermal expansion, button cap erosion, and load orifice retention.

System Description

Basic System

The basic schematic of the system tested is shown in Figure A-1. The vortex valve receives gas from a supply source via a plenum chamber and vent orifice assembly. The vortex valve control flow originates at a source which provides a constant control supply. The vortex valve control flow is modulated by a vented manual control valve, which in turn is operated by a pneumatic input signal from a 2-position four-way solenoid valve.



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Figure A-1 - Basic Test Schematic for the Single Vortex Valve Test

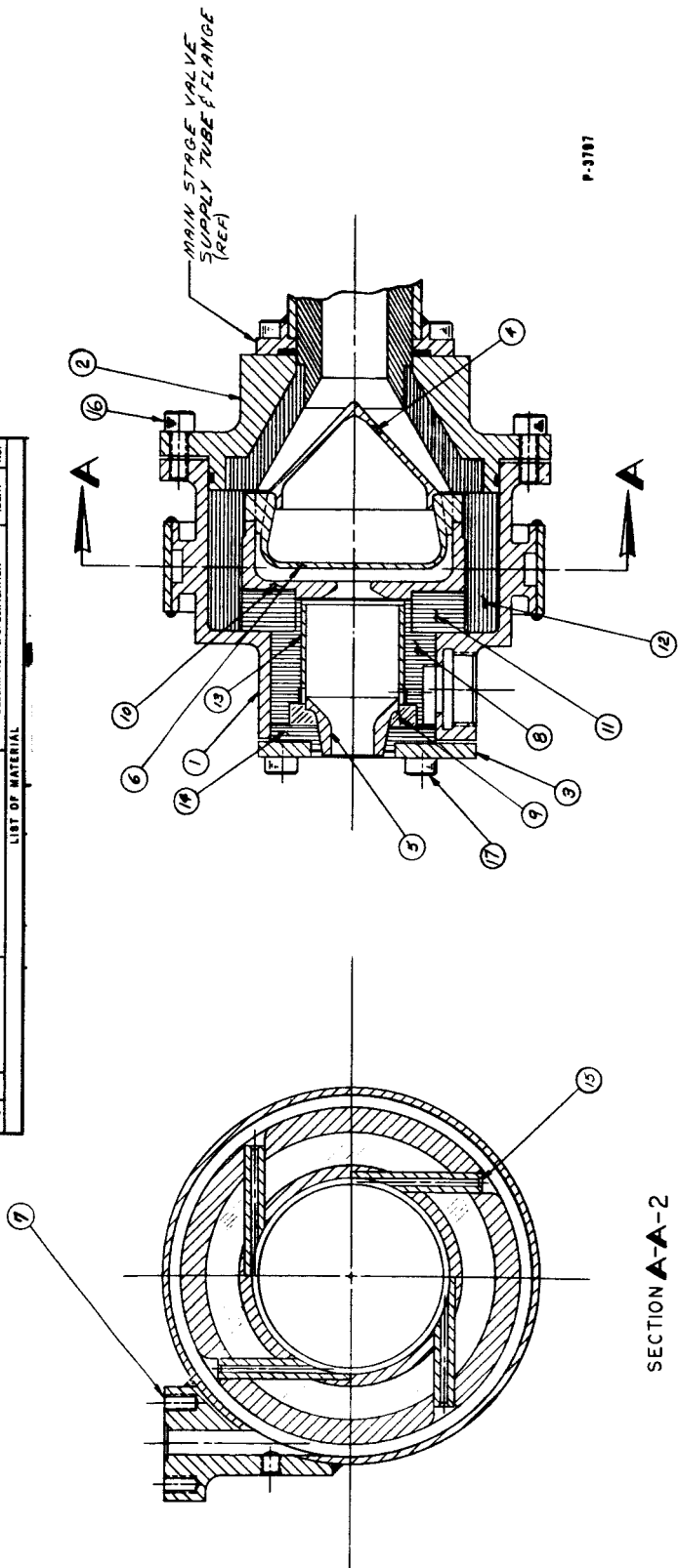
Vortex Valve

The vortex valve as tested is shown in Figure A-2, A-3, and A-4. The vortex chamber, the button assembly, the outlet orifice, and the valve plenum chamber liner were all made from silver-infiltrated tungsten. The material used for the orifice retaining plate, the valve port ring, end cap, and valve housing was 300 series stainless steel. The insulation used in the valve construction consisted of carbon phenolic (Fiberite MX-4926), silica phenolic (Fiberite MX-2600), and ATJ graphite. The vortex chamber insulation was constructed, using carbon phenolic as inner insulation against the vortex chamber and silica phenolic as outer insulation against the valve housing. The end cap, outlet orifice, and valve plenum chamber insulation were made from carbon phenolic. The orifice retainer was made from ATJ graphite. The control flow injectors were made from TZM molybdenum.

Plenum Chamber and Vent Orifice Assembly

The plenum chamber and vent orifice assembly is shown in Figures A-5 and A-6. The housing for the assembly was fabricated by welding together a modified 5500°F SPGG aft closure and a plenum chamber-supply tube assembly made from 1020 carbon steel. The face

QTY. DRAW REQD. SIZE	PART NO.	DESCRIPTION	MATERIAL DESCRIPTION & SPECIFICATION	CODE IDENT	ITEM NO.
4	STOCK	SCR 500 HD CAP	.912-24 UNF-30X.6210		17
6	STOCK	SCR 500 HD CAP	.912-24 UNF-30X.7510		16
4	B 2159113	INJECTOR			15
1	B 2161555	INSULATOR-PLENUM CHAMBER ORIFICE			14
1	B 2161354	LINER-PLENUM CHAMBER			13
1	C 2161186-3	VALVE BODY INSULATOR			12
1	C 2161186-1	VALVE BODY INSULATOR			11
1	C 2161355-1	VORTEX CHAMBER			10
1	B 2161556	CARBON INSULATOR			9
1	C 2161356	INSULATOR, PLENUM CHAMBER			8
1	D 2159097	VALVE PORT RING ASSY			7
1	D 2161184	BUTTON BODY VORTEX VALVE			6
1	B 2161557	PLENUM CHAMBER ORIFICE			5
1	C 2161185-3	BUTTON CAP VORTEX VALVE			4
1	B 2161558	EXHAUST FLANGE-VALVE			3
1	C 2161187	END CAP-VALVE ASSY			2
1	D 2161185-1	VALVE BODY			1



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SECTION A-A-2

Figure A-2 - Assembly of Vortex Valve and Injector Load Orifice

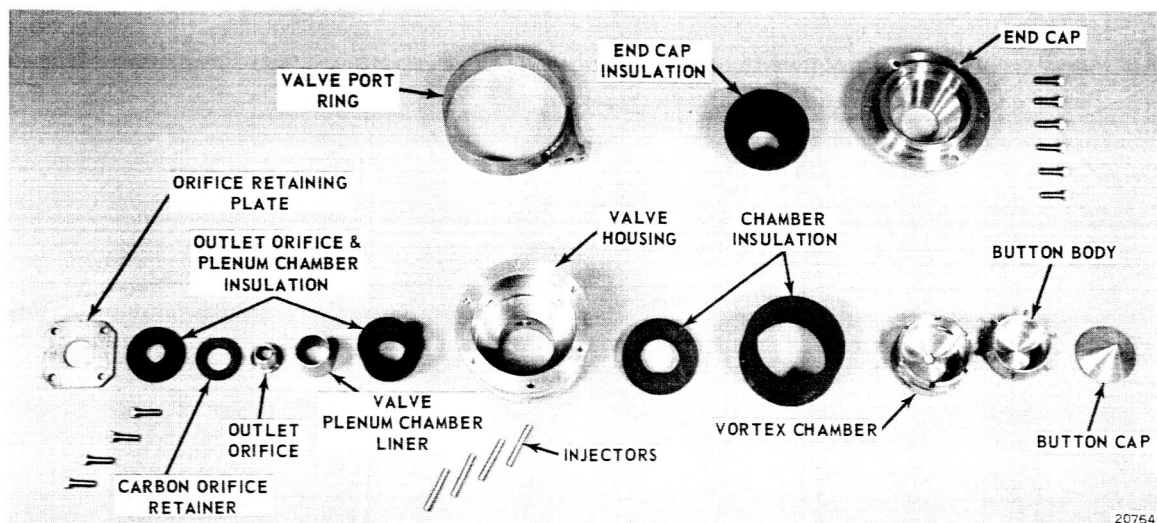


Figure A-3 - Vortex Valve Components

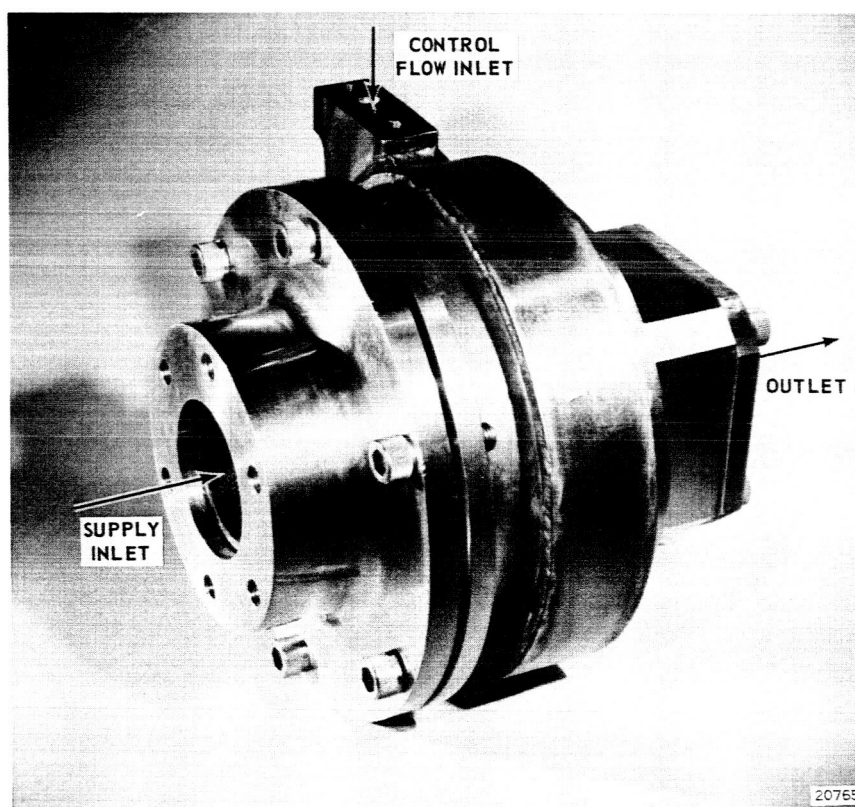


Figure A-4 - Vortex Valve Assembly

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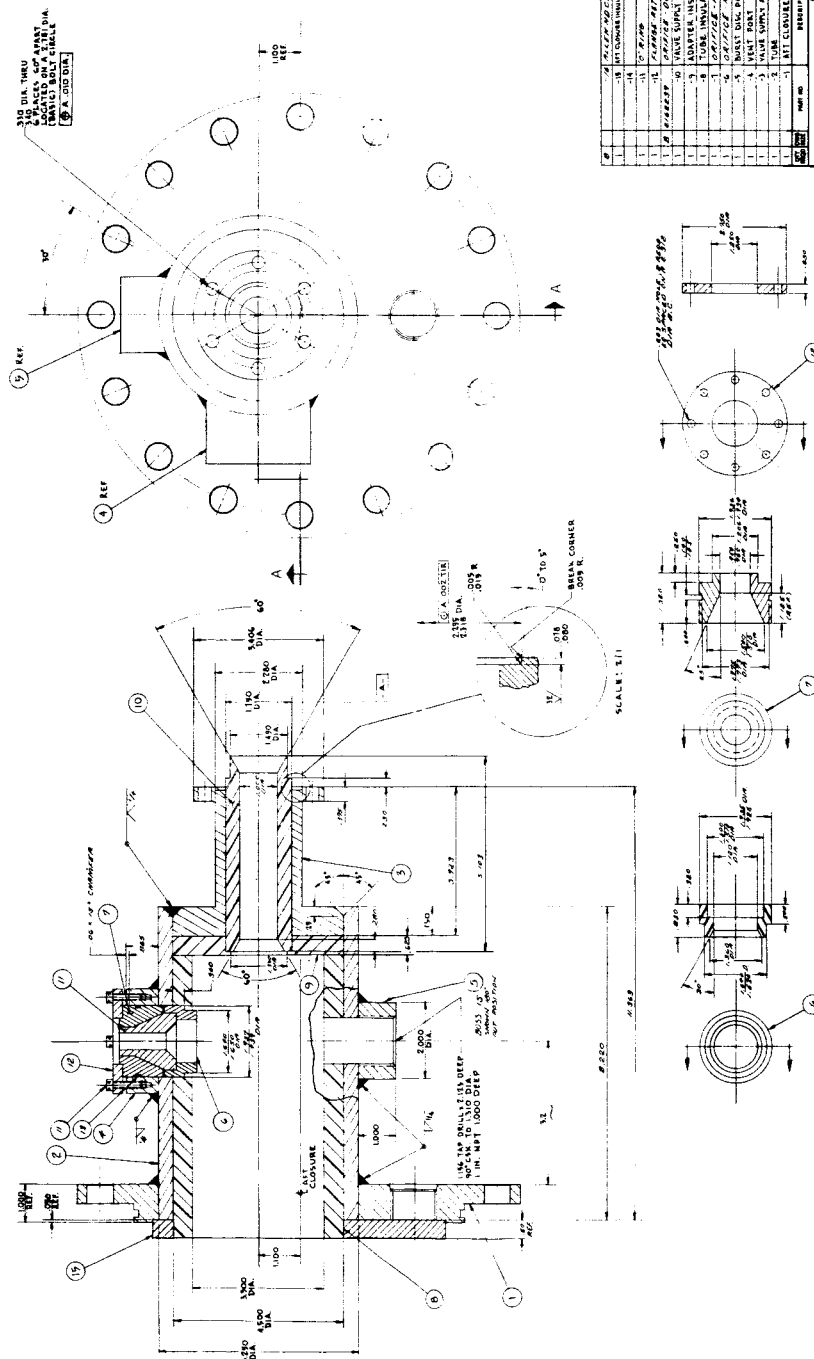
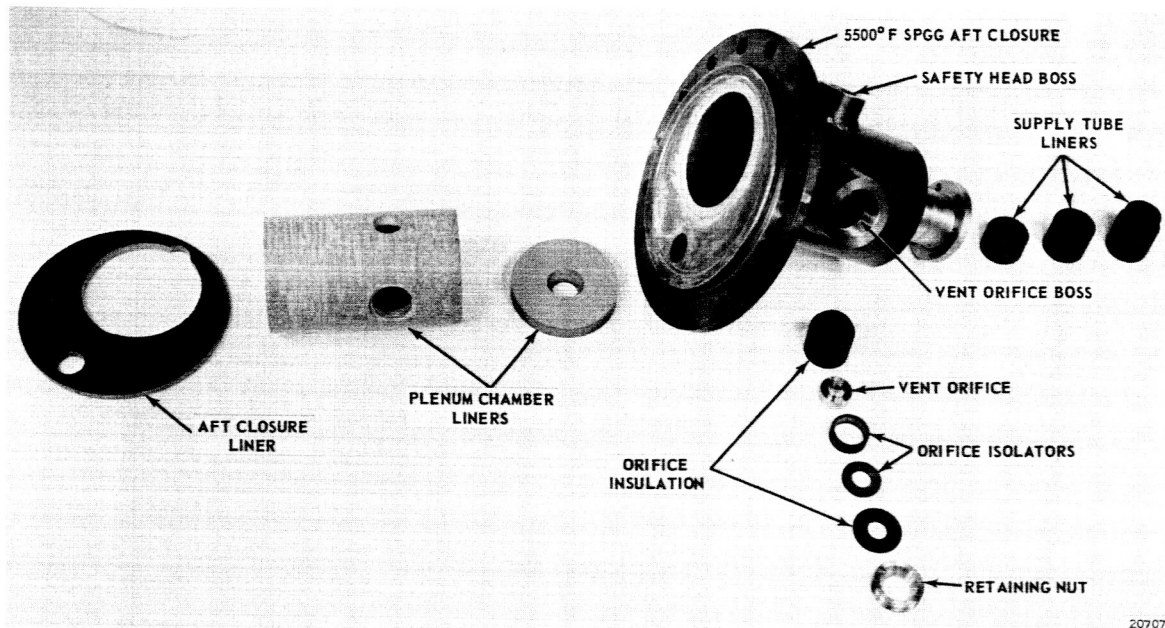


Figure A-5 - Plenum Chamber and Vent Orifice Assembly



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Figure A-6 - Plenum Chamber and Vent Orifice Assembly

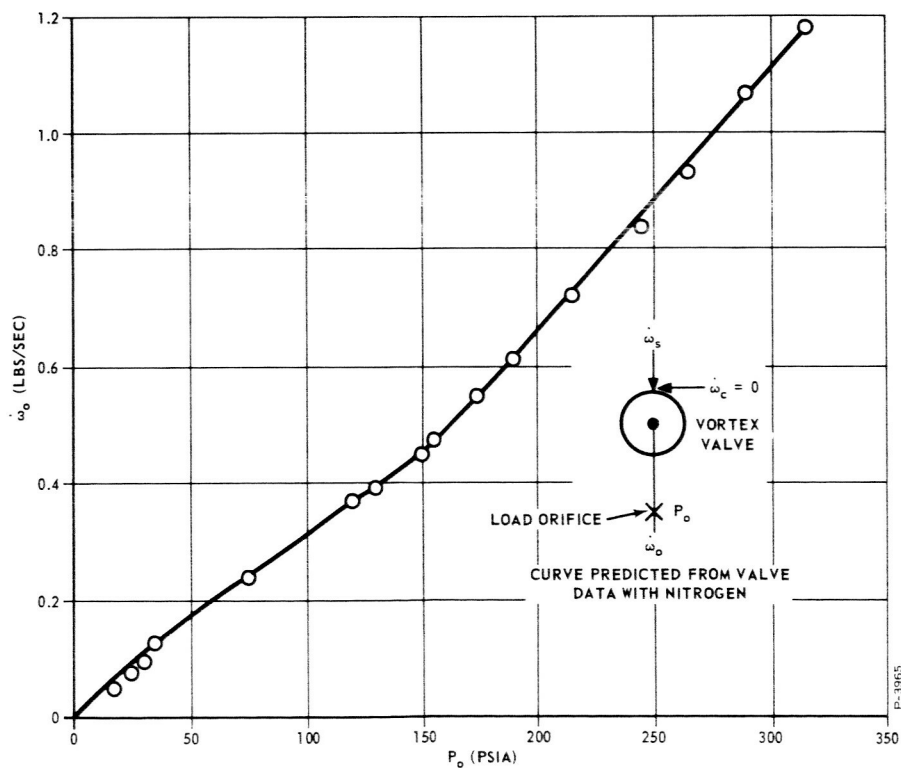


Figure A-7 - Vortex Valve and Load Orifice Flow Characteristics for PJS_c Solid Propellant Hot Gas ($\dot{\omega}_o$ Versus P_o)

of the aft closure was lined with asbestos phenolic and silica phenolic was used to line the plenum chamber. The supply tube liners and the vent orifice insulation were made from carbon phenolic. The orifice isolators were made from ATJ graphite and the vent orifice was made from tungsten. All of the insulation and the vent orifice, except the supply liners, were bonded in place with a high temperature epoxy.

Cold Gas Test

The purpose of the cold gas testing was to determine the steady-state performance characteristics of the single vortex valve SITVC System and to verify the intended performance of the System's various components prior to the hot gas test. The System's vent and flow control orifices and the control valve were calibrated in a conventional manner using nitrogen. The vortex valve and system test results are discussed below.

Vortex Valve Performance

The cold gas testing of the vortex valve was performed to obtain its flow and turndown performance characteristics. The vortex valve and load orifice flow performance was obtained by flowing nitrogen through the valve assembly at various supply pressures that matched the valve's predicted operating range during the hot gas test. The data recorded was P_o , the outlet pressure measured at the vortex valve load orifice, P_s , the valve's supply pressure, and \dot{w}_o , the weight flow of nitrogen through the valve. The weight flow of nitrogen was converted to an equivalent weight flow of 5500°F solid propellant and the results were plotted as \dot{w}_o vs. P_o as shown in Figure A-7 and \dot{w}_o vs. P_s as shown in Figure A-8.

The vortex valve turndown performance was obtained by varying the flow of nitrogen into the valve control injectors while regulating the valve supply flow at a constant pressure. The data obtained was plotted as $\dot{w}_o/\dot{w}_{o_{max}}$ vs. P_c/P_s and $\dot{w}_c/\dot{w}_{o_{max}}$ vs. P_c/P_s , as shown in Figure A-9, in which \dot{w}_o is the total weight flow of the valve, \dot{w}_c is the control weight flow, P_c is the control pressure and P_s is the supply pressure. The total turndown obtained for the vortex valve was 5.55 to 1 at P_c/P_s equal to 1.40.

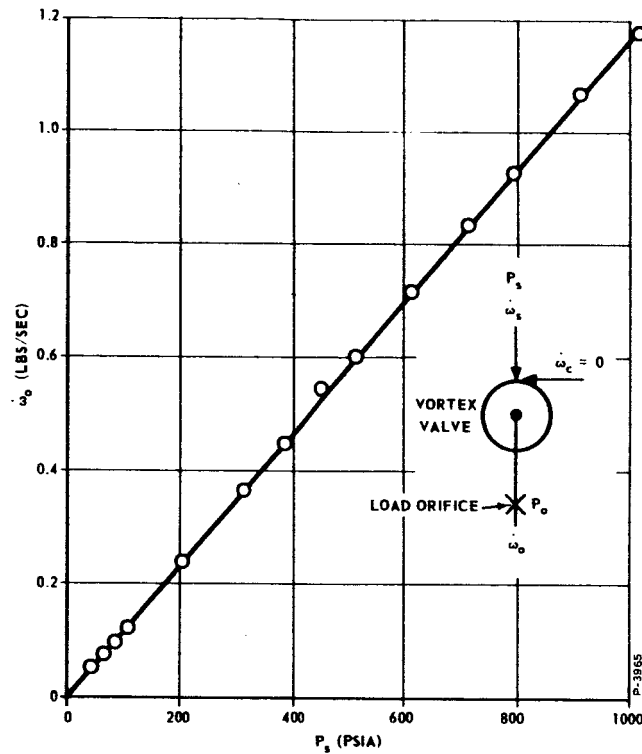


Figure A-8 - Vortex Valve and Load Orifice Flow Characteristics for P J S_c Solid Propellant Hot Gas ($\dot{\omega}_o$ Versus P_s)

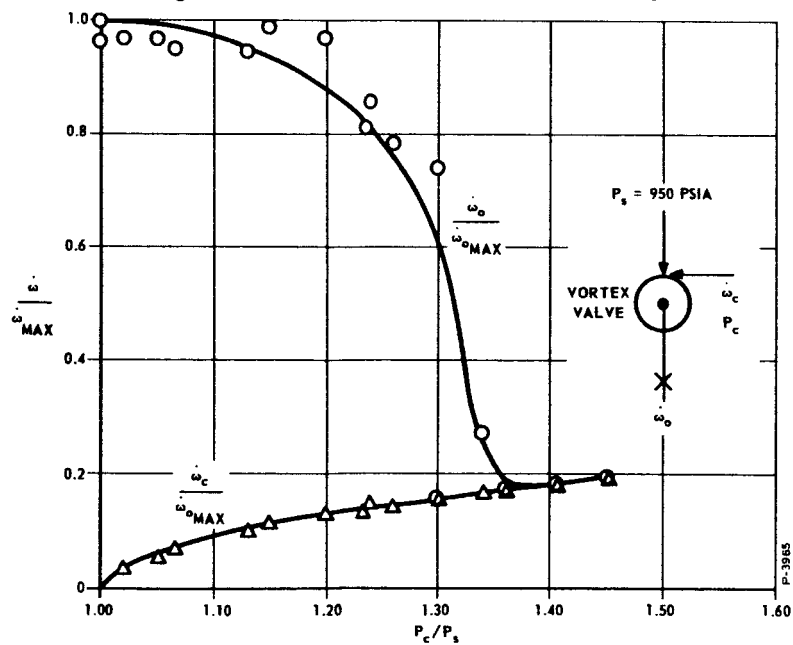


Figure A-9 - Vortex Valve and Load Orifice Turndown Characteristics on Nitrogen at 950 Psia

System Performance

The steady-state performance of the basic system shown in Figure 1 was obtained by adding to it a pneumatic input and nitrogen control and valve supplies and operating the resulting system in a simulated hot gas test. The resulting cold gas test arrangement is shown schematically in Figure A-10.

The flow control orifice in the valve supply line was sized to provide the equivalent flow that the 5500°F SPGG would produce when the vortex valve was at full turndown. The resulting nitrogen valve supply did not duplicate the SPGG valve supply, because as the vortex valve modulates the hot gas flow, P_s will vary, resulting in a variation in SPGG supply flow. No variation in nitrogen supply flow occurred due to the choked orifice upstream of the vortex valve.

The stroke of the control valve was sized to keep to the control flow at a level such that the vortex valve restriction would keep P_s at 515 psia minimum. The reason for this will be discussed in the hot gas test section. The control valve operated in full open-full closed manner as controlled by the solenoid valve. The solenoid valve was controlled from a sequence device which produced timed-stepped electrical signals. The "sequencer" was also used to control the hot gas test.

The results of the system cold gas test are shown in Figure A-11. As can be seen, the valve supply pressure, P_s , varied as intended from 965 psia to 515 psia with a resulting variation in P_o from 165 psia to 255 psia. The resulting flow modulation from this test was 1.8 to 1. The lag in the non-square pressure outputs P_s , P_o , and P_c from a square wave pressure input P_i was caused by the relatively large volume under compression in the valve supply line, and the response characteristics of the manual valve.

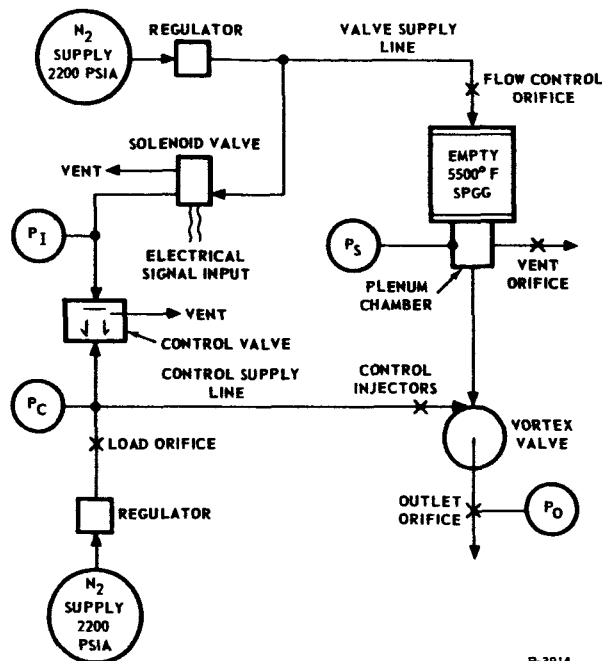
The cold gas testing indicated that the 5500°F SITVC Single Vortex Valve System will operate as predicted when coupled to the solid propellant gas generators.

Hot Gas Test

The purpose of the hot gas test was to demonstrate flow modulation of the 5500°F aluminized gas using a single vortex valve and 2000°F nonaluminized gas for control, and also to verify the structural integrity of the new vortex valve design.

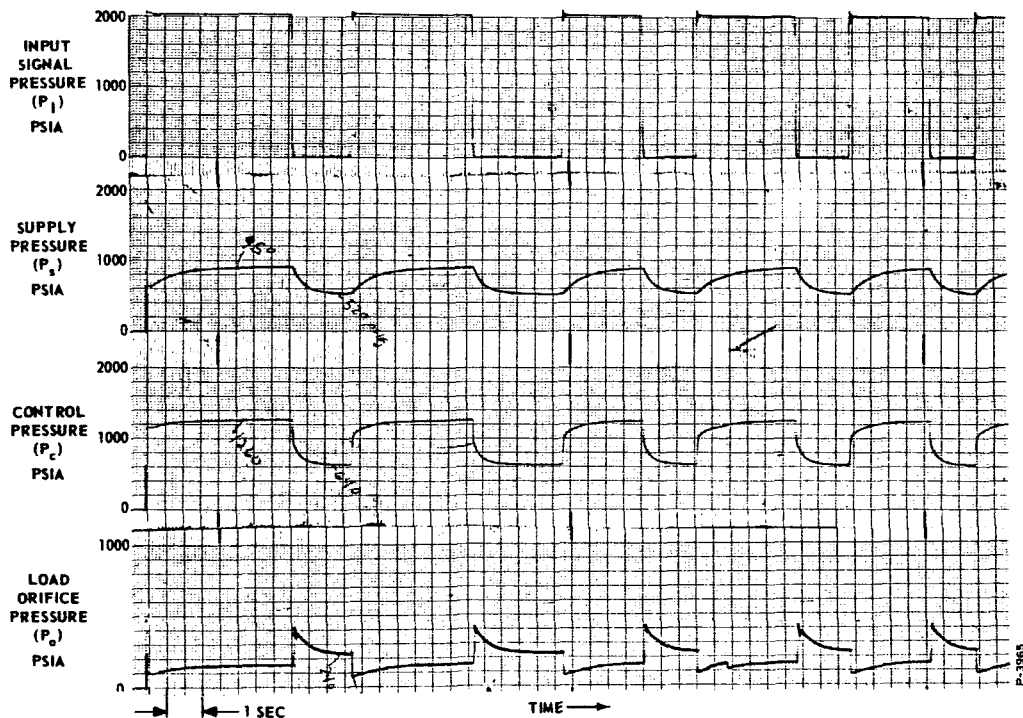
Test System

The hot gas test of the basic system shown in Figure A-1 was obtained by adding to the basic system a pneumatic input, a 5500°F



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Figure A-10 - Test Schematic for Cold Gas Test of 5500°F SITVC System - Single Vortex Valve



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Figure A-11 - Single Vortex Valve System Cold Gas Test Results

SPGG vortex valve supply, and a 2000°F SPGG control supply. The resulting hot gas test arrangement is shown in Figures A-12, A-13, and A-14.

The supply vent orifice was sized to keep $P_{s \text{ max}}$ limited to 965 psia when the vortex valve was at full turndown. This was done because of control flow limitations and was determined as follows: with $P_{g \text{ max}}$ equal to 2265 psia, the control supply load orifice flowing sonic, and the critical pressure ratio of Omax propellant being 0.547 the value of $P_{c \text{ max}}$ was found to be:

$$P_{c \text{ max}} = P_g \times \left(\frac{P_d}{P_a \text{ Crit}} \right) = 2265 \times 0.547 = 1235 \text{ psia}$$

The P_c/P_s ratio required to obtain full vortex valve turndown with the stainless steel valves was found to be 1.28 and $P_{s \text{ max}}$ is then:

$$P_{s \text{ max}} = \frac{P_{c \text{ max}}}{1.28} = \frac{1235}{1.28} = 965 \text{ psia.}$$

The control flow valve and load orifices were sized to obtain the desired control flow and generator operating pressure. As mentioned previously, the stroke of the control valve was sized to limit $P_{c \text{ min}}$ to 515 psia. This was done to limit the possibility of irregular burning of the 5500°F SPGG at low pressures.

The single vortex valve SITVC System was to be controlled by a sequencer during the hot gas test. The sequencer was designed to start the required cameras, recorders, timers, and ignite the two SPGG's and operate the control solenoid valve at predetermined timed intervals.

Test Results

All of the hot gas test objectives were not met, due to a misfire of the 2000°F SPGG, which was to provide the System's control flow. The misfire was caused by an open line in the 2000°F SPGG ignitor circuit. The test results obtained with only the 5500°F SPGG in operation are discussed below.

The test data obtained is plotted in Figure A-15. This is a plot of P_s and P_o versus time starting with the ignition of the 5500°F SPGG as time zero. The hot gas flow through the vortex valve and the plenum

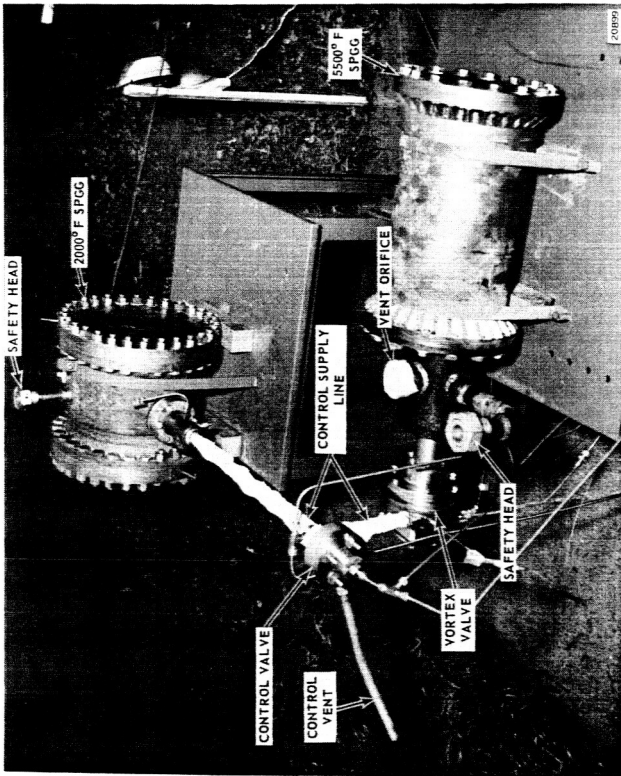


Figure A-13 - 5500°F SITVC System - Single Vortex Valve Hot Gas Test Arrangement

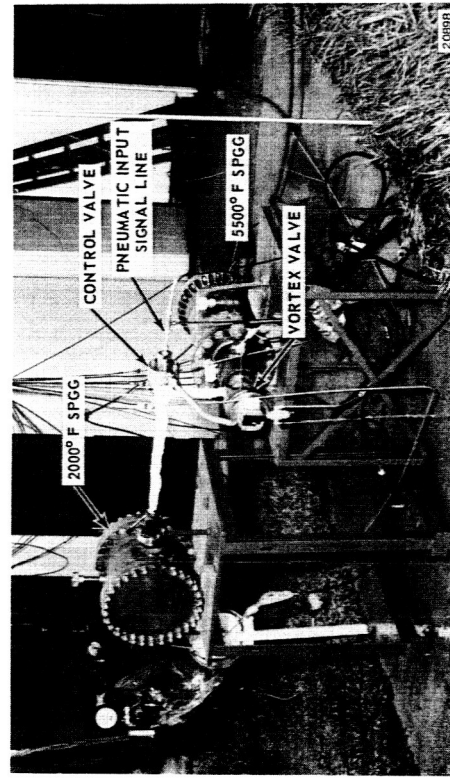


Figure A-14 - Test Schematic Hot Gas Test of 5500°F SITVC System - Single Vortex Valve

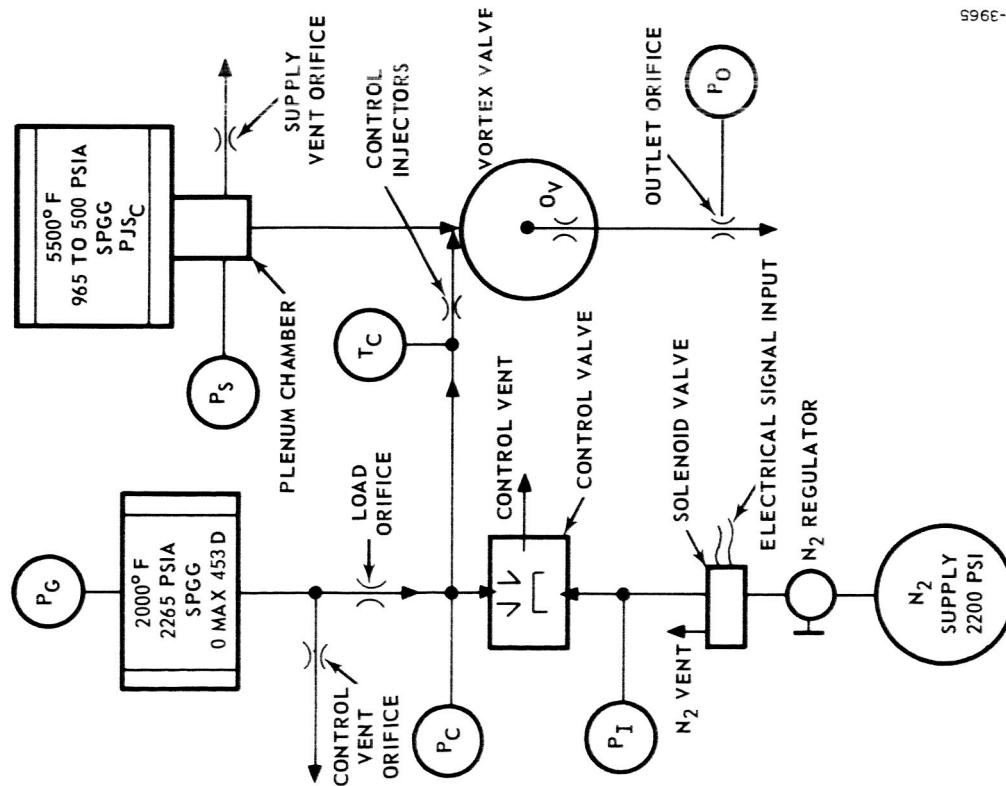


Figure A-12 - Test Schematic Hot Gas Test of 5500°F SITVC System - Single Vortex Valve

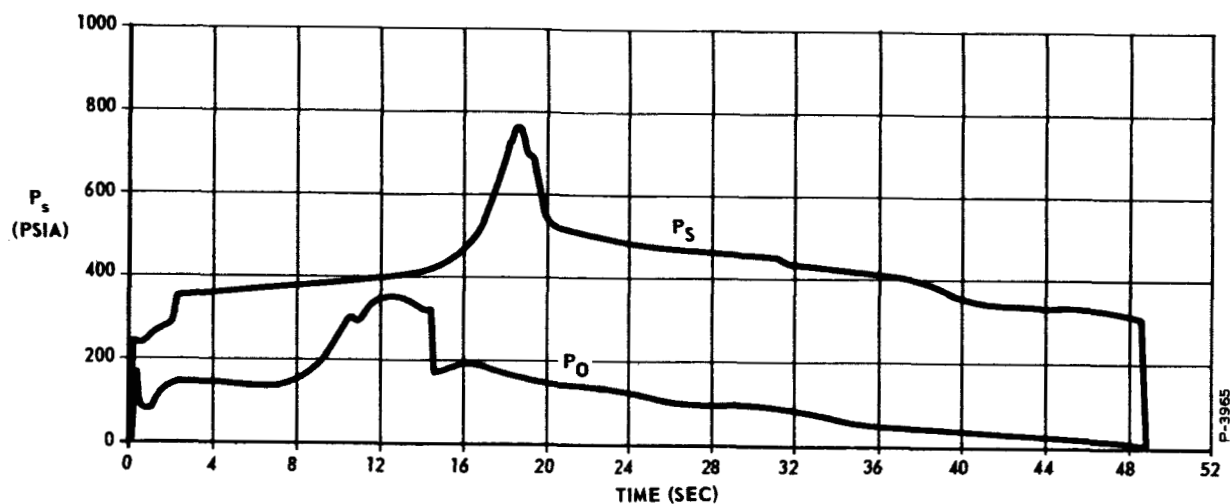


Figure A-15 - 5500°F SITVC System - Single Vortex Valve Test Results

chamber vent orifice were calculated from their individual calibration curves that were obtained from the cold gas tests.

The SPGG outputs in the following discussions were determined from equation 1.

$$\dot{\omega}_g = A P r = A P c p^\eta \quad (1)$$

where

A = area of the grain = 48 in²

P = propellant density = 0.0637 lb/in³

r = burn rate (in/sec)

c = constant dependent on grain conditioning

η = 0.3 (constant dependent on grain material)

p = generator burn pressure (psia)

The value of constant, c , was calculated by first determining that the average SPGG burn pressure, \bar{P}_s , was 417.5 psia from the plot of P_s vs. time in Figure A-15. Then the average weight flow of propellant for the test was found by:

$$\bar{\omega}_g = \frac{\text{Grain Wt.}}{\text{Total Burn Time}} = \frac{42.25}{48.8} = 0.865 \text{ lb/sec.}$$

With the use of $\bar{\dot{\omega}}_g$ and \bar{P}_s and equation 1 the test value of c was found to be:

$$c = \frac{\bar{\dot{\omega}}_g}{A \rho P^\eta} = \frac{0.865}{48(0.0637) 417.5^{0.2}} = 0.0464$$

This value of c was verified by using it to calculate a burn rate and comparing the calculated burn rate with the actual burn rate as follows:

$$r_{(\text{Calc.})} = c P^\eta = 0.0464 (417.5)^{0.3} = 0.283 \text{ in/sec}$$

$$r_{(\text{Actual})} = \frac{\text{Length}}{\text{Time}} = \frac{13.81}{48.8} = 0.283 \text{ in/sec.}$$

At time zero, the 5500°F SPGG ignited. The lack of a recorded ignition P_s spike was due to the damping effect of the long pressure line that connected the pressure sensing point to the transducer. The low level of P_s for the first 2 seconds was probably caused by the SPGG grain not burning on its full face. The area of the grain that was burning at time 0.8 second was determined as follows:

$$\dot{\omega}_o = 0.28 \text{ lb/sec. @ } P_o = 75 \text{ psia}$$

$$\dot{\omega}_{\text{Vent Orifice}} = 0.23 \text{ lb/sec @ } P_s = 240 \text{ psia}$$

$$\dot{\omega}_g = \dot{\omega}_o + \dot{\omega}_{\text{v.o.}} = 0.28 + 0.23 = 0.51 \text{ lb/sec}$$

$$A = \frac{\dot{\omega}_g}{\rho c P^\eta} = \frac{0.51}{0.0637 (0.0464) 240^{0.3}} = 33.2 \text{ in}^2$$

The resulting burn area was less than the total grain area of 48 in². At time 2 seconds P_s rose rapidly from 285 to 360 psia indicating that the SPGG began operating normally at this point. An insufficient booster charge was the probable cause of this partial face burning.

At time 3 seconds, the pressures stabilized at $P_s = 360$ psia and $P_o = 150$ psia. Using the values of P_s and P_o and Figures A-7 and A-8 the flow through the vortex valve was found to be:

$$\dot{\omega}_o = 0.45 \text{ lb/sec @ } P_o = 150 \text{ psia}$$

$$\dot{\omega}_s = 0.42 \text{ lb/sec @ } P_s = 360 \text{ psia}$$

This comparison indicates that P_o provided a good correlation of the vortex valve output flow rate. With $P_s = 360$ psia the SPGG output, $\dot{\omega}_g$, and the vent orifice output, $\dot{\omega}_{v.o.}$, was found to be:

$$\begin{aligned}\dot{\omega}_g &= 0.832 \text{ lb/sec} \\ \dot{\omega}_{v.o.} &= 0.35 \text{ lb/sec}\end{aligned}$$

Therefore, $\dot{\omega}_g = 0.832 = \dot{\omega}_o + \dot{\omega}_{v.o.} = 0.45 + 0.35 = 0.80 \text{ lbs/sec}$. This result indicates that the test data was able to supply good flow correlation between all the active system components.

At time 4 seconds P_o started a slight decline while P_s began a moderate incline which lasted to 14 seconds. This condition appears to have been the result of a reduction in the flow area through the vortex valve caused by thermal expansion of the vortex valve internal parts.

The vortex valve outlet pressure, P_o , began a rapid pressure rise from 140 psia at 7 seconds to 300 psia at 10.6 seconds and then remained noisy to 14.5 seconds at which time it dropped to 170 psia. The P_o values in this time range were abnormal as can be seen at time 10.6 seconds when the value of P_o indicates that the vortex valve had an output flow rate of 1.11 lb/sec which was greater than the SPGG output of 0.854 lb/sec. The erratic behavior of P_o could have been caused by a mechanical loading of the transducer due to expanding valve insulation or by the transducer sensing conditions in the valve plenum chamber through some leak path. At some unknown time, the leading edge of the button burned through, but there is no data which indicates the failure time.

At time 14 seconds, the rate of increase of P_s became more rapid until at 18.6 seconds, P_s reached a maximum value of 760 psia and then began a rapid descent to 500 psia at 22 seconds. This rapid pressure rise was the result of the continued reduction in valve flow area caused by thermal expansion and part creepage. The rapid decrease in pressure was the result of a hole opening through the middle of the button and thereby relieving the restriction caused by thermal expansion.

At time 22 seconds with $P_s = 500$ psia and $P_o = 140$ psia the flow correlation became reasonable again as can be seen by:

$$\begin{aligned}\dot{\omega}_o &= 0.42 \text{ lb/sec @ } P_o = 140 \text{ psia} \\ \dot{\omega}_{v.o.} &= 0.485 \text{ lb/sec @ } P_s = 500 \text{ psia} \\ \dot{\omega}_g &= 0.914 = \dot{\omega}_o + \dot{\omega}_{v.o.} = 0.42 + 0.485 = 0.905 \text{ lb/sec}\end{aligned}$$

This type of flow correlation remained until time 31 seconds. After 31 seconds the flow correlation again deteriorated. Flow correlation is lost because the carbon orifice retainer failed about the P_o sensing line, venting P_o to atmosphere.

Material and Design Evaluation

The vortex valve body and end cap suffered no ill affects from the hot gas test, as can be seen in Figures A-16 and A-19. Both parts appear to be usable without modifications. The valve control port ring received some erosion on its inner surface from the back flow of 5500°F gas through the injectors. This was caused by the lack of control pressure which would have presented the backflow. This ring will not be used in further testing.

The plenum chamber and vent orifice housing remained in good general condition throughout the test. The vent orifice boss suffered some erosion, but this damage can be repaired so that the housing can be used in further testing.

The carbon phenolic insulation used throughout the test system survived very well. The valve supply tube insulation shown in Figure A-17 and A-18 contained the flow of 5500°F aluminized gas for the duration of the test with only expected erosion. This supply tube was constructed in two sections, each with a different fabrication method. The upstream section as indicated in Figure A-17 was molded with the laminates perpendicular to the tube center line. The downstream section was molded with the laminates at a 30 degree angle to the center of the tube. From the appearances of tube cross-section, the tube section with laminates at 30 degrees to the tube center line provided the best resistance to erosion. One additional feature of the valve supply tube insulation that worked successfully was the interlocking arrangement between the tube insulation and the end cap insulation, as shown in Figure A-18.

The carbon phenolic valve housing and outlet orifice insulation survived the test with no apparent failures, as is shown in Figures A-19 and A-20. One unexpected result from the test was the high strength of carbon phenolic char. It was expected that as the carbon phenolic charred, and the mating tungsten parts tried to expand, that the carbon phenolic char would crush and not resist the expansion of the tungsten

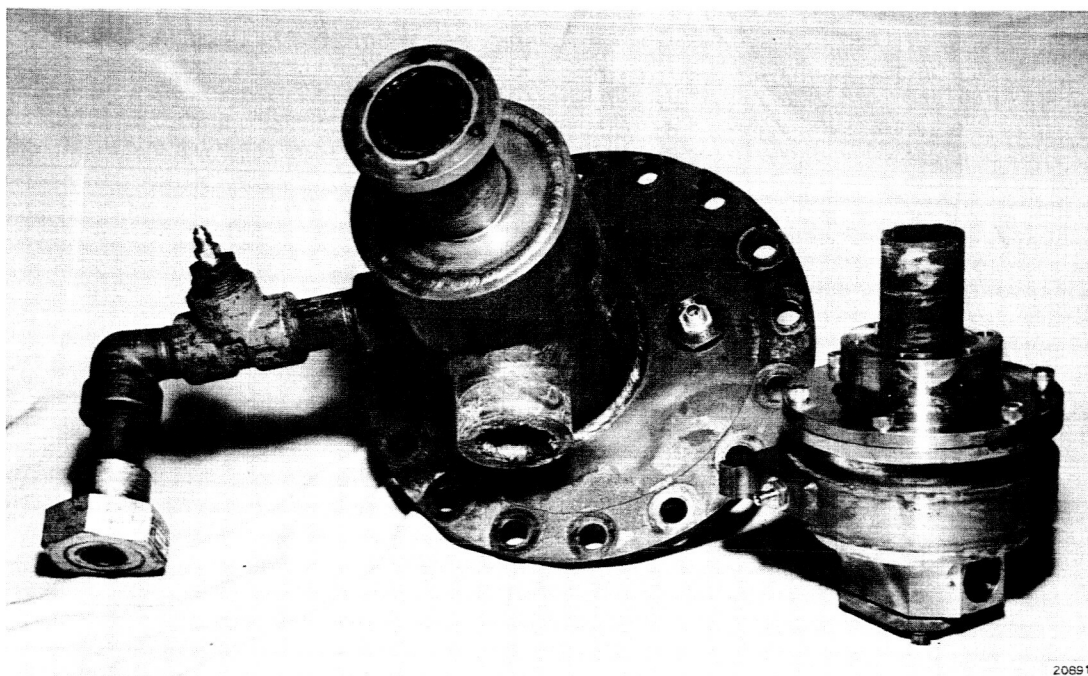


Figure A-16 - Vortex Valve Assembly, Plenum Chamber and Vent Orifice Assembly

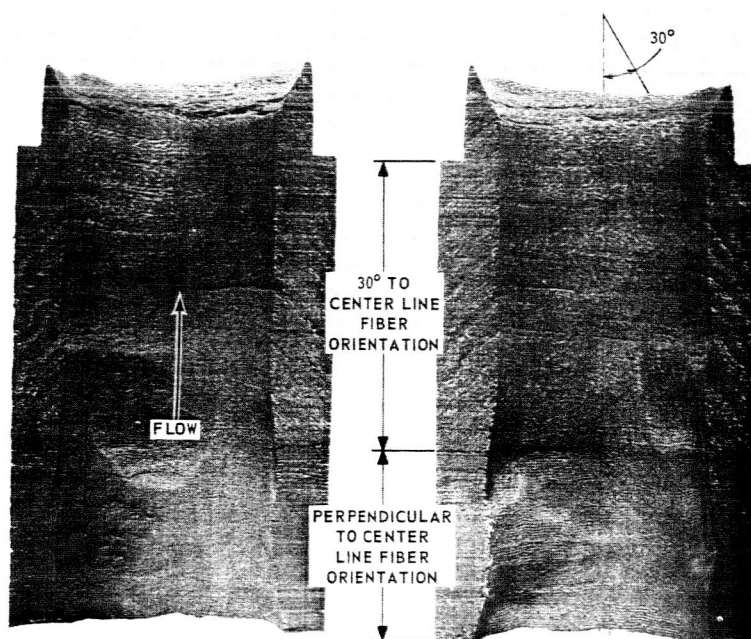


Figure A-17 - Valve Supply Tube Insulation

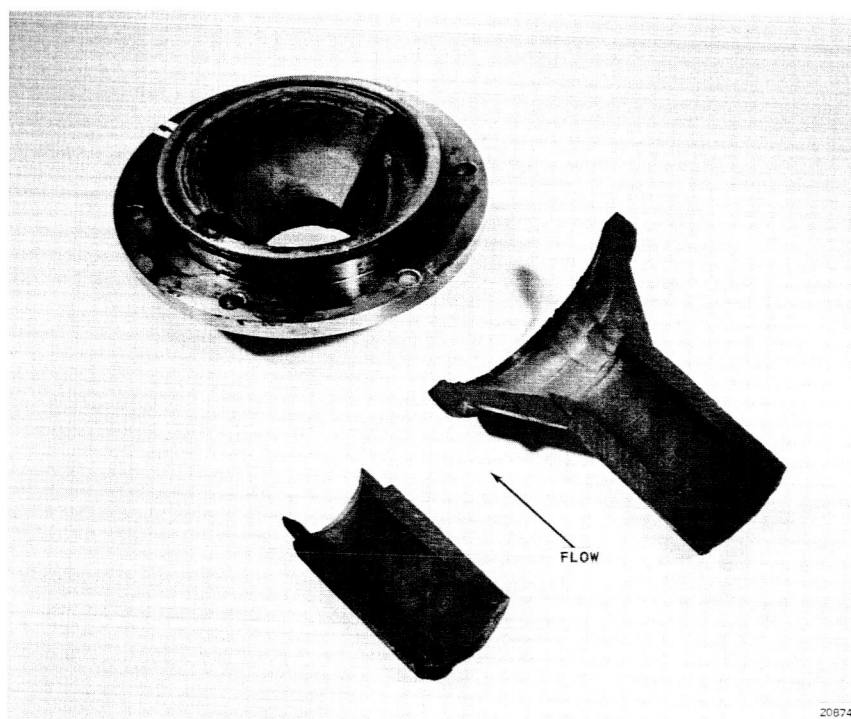


Figure A-18 - Valve End Cap, End Cap Insulation, and Supply Tube Insulation

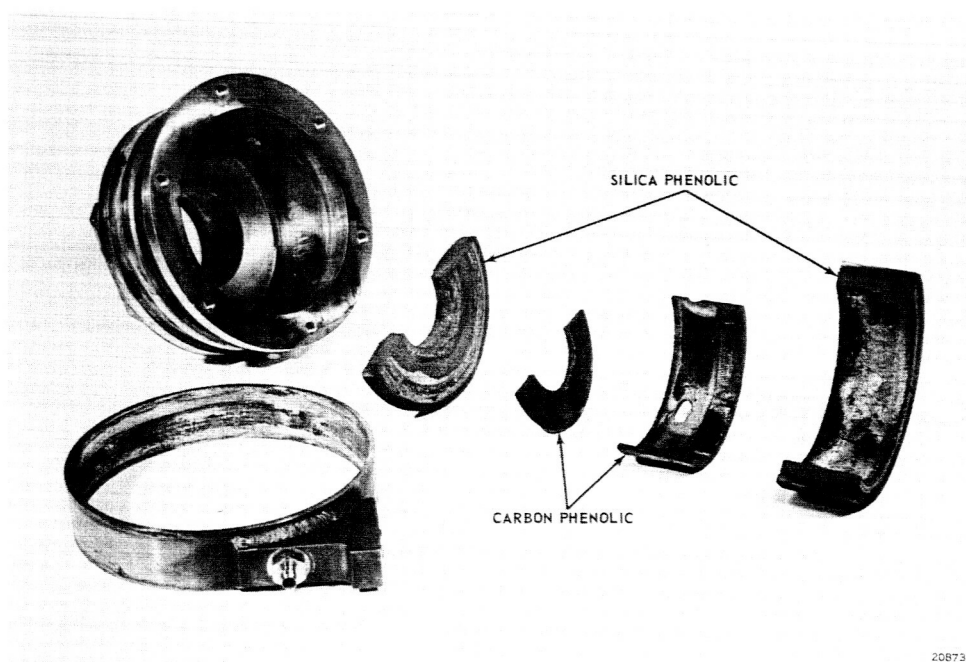


Figure A-19 - Valve HSG, Insulation, and Control Port Ring

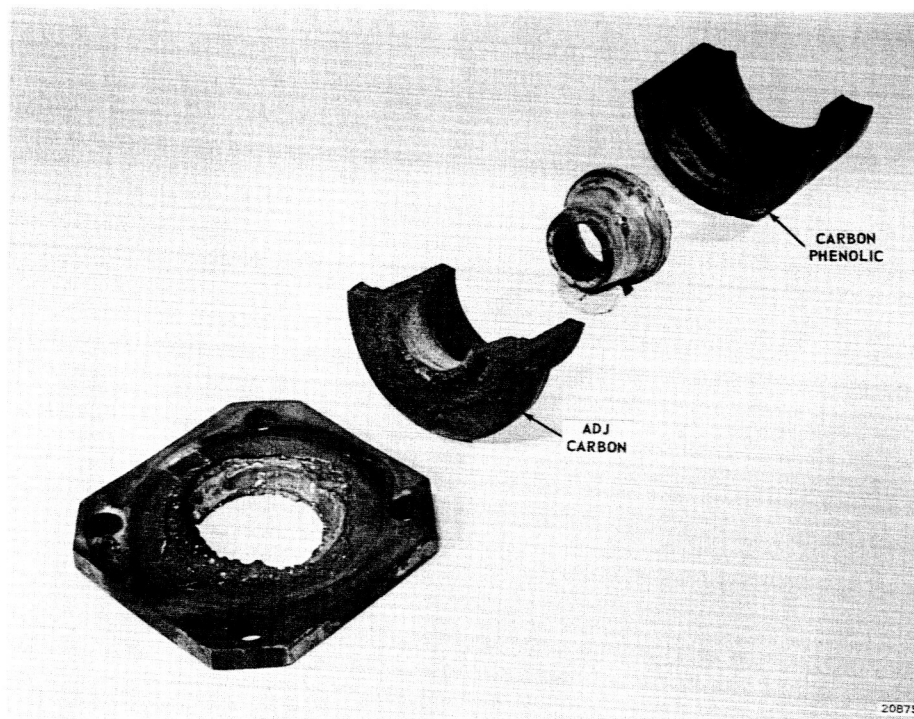


Figure A-20 - Valve Outlet Orifice, Insulation and Retainer Plate

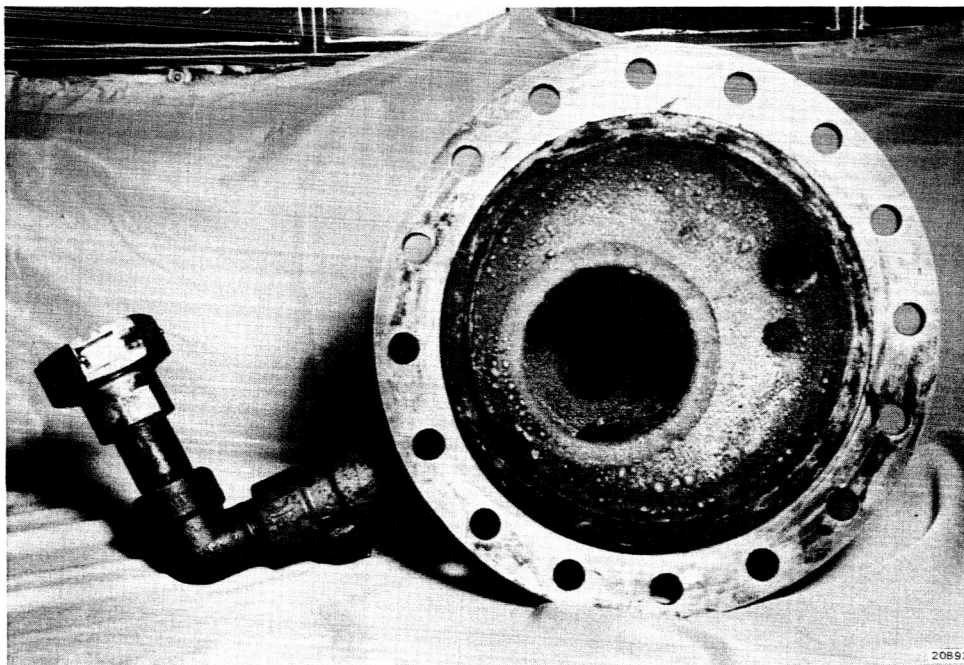


Figure A-21 - SPGG AFT Closure and Plenum Chamber

parts. This did not happen, and the tungsten parts yielded plastically and were distorted. This distortion of the tungsten vortex chamber could have been one of the causes for the restriction in the vortex valve flow area, resulting in rapid supply pressure buildup prior to the button failure.

The only carbon phenolic part to fail was the insulation used in housing the SPGG plenum chamber vent orifice. This part eroded and allowed gas to flow around the outside of the orifice. This problem can be corrected by increasing the thickness of insulation in the critical areas and by using insulation with laminates molded at 30 degrees to the center line.

The ATJ carbon part that was used to retain the valve outlet orifice did not survive the test. This part cracked and crumbled, resulting in the loss of a valid P_o measurement in the last part of the test. This condition can be corrected by using carbon phenolic as a replacement material.

The silica phenolic parts used in the SPGG plenum chamber produced good results as shown in Figure A-21. There appears to be no need for changing the design or material in this area.

The tungsten vortex valve outlet orifice and vent orifice completed the test with only normal degradation. Both of the orifices retained their original sizes. The only portions of the orifice region that need redesign are the orifice retention and sealing techniques.

The tungsten vortex chamber, as mentioned previously, suffered from distortion. This distortion can be seen in Figures A-22, A-23, and A-25. The chamber distortions are attributed to two conditions: The diametrical distortion of the chamber was due to the chamber's outside diameter being restrained by the carbon phenolic during the chamber's heat up. This condition can be improved by redesigning the chamber retention method. The "S" shaped distortion of the chamber's face was caused by the expansion of the outlet orifice insulation, the pressure drop across the chamber outlet hole, and the soft plastic condition of the tungsten material when it is at operating temperature. This problem can be remedied by placing support material behind the outlet section of the chamber and by providing clearance between the insulation and tungsten to allow for the tungsten expansion.

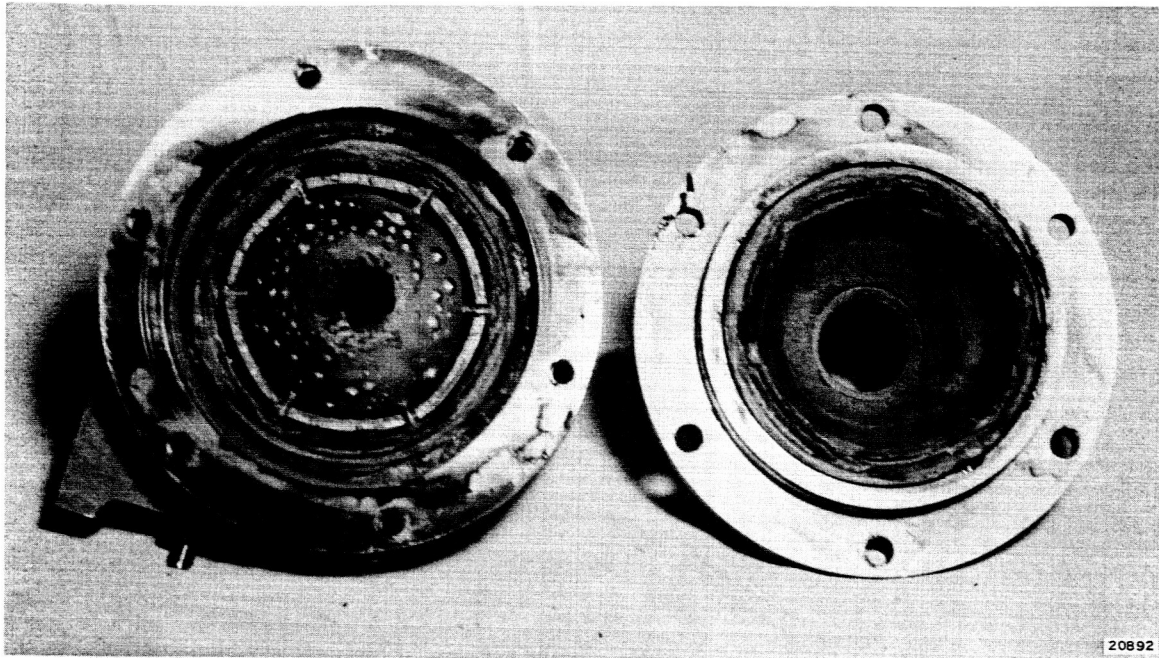


Figure A-22 - Valve End Cap, Body, and Button

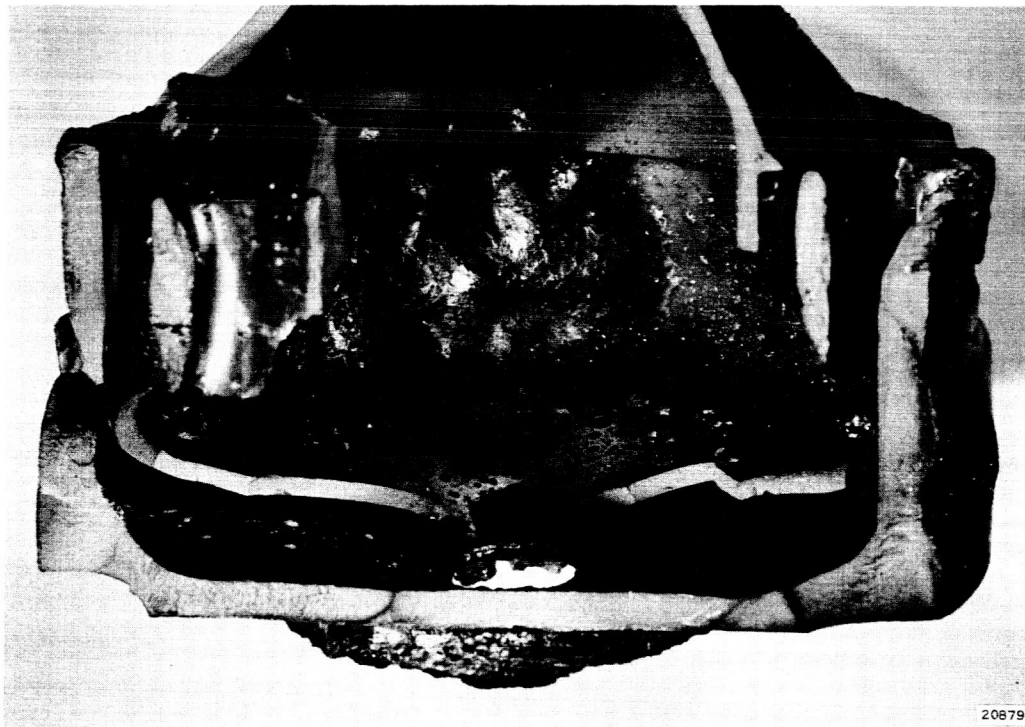


Figure A-23 - Valve Button and Vortex Chamber

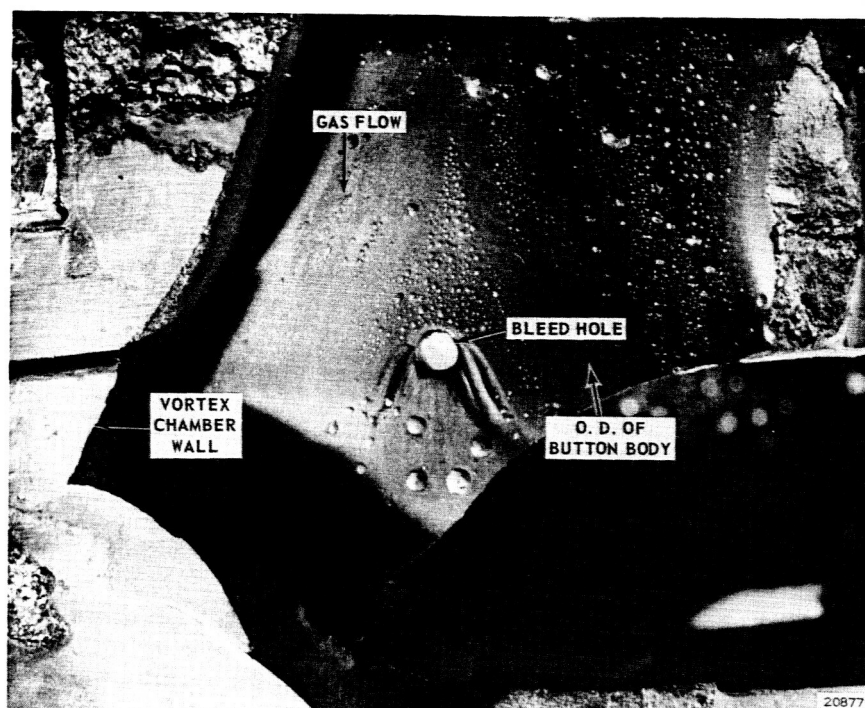


Figure A-24 - Valve Button Body Air Bleed Hole

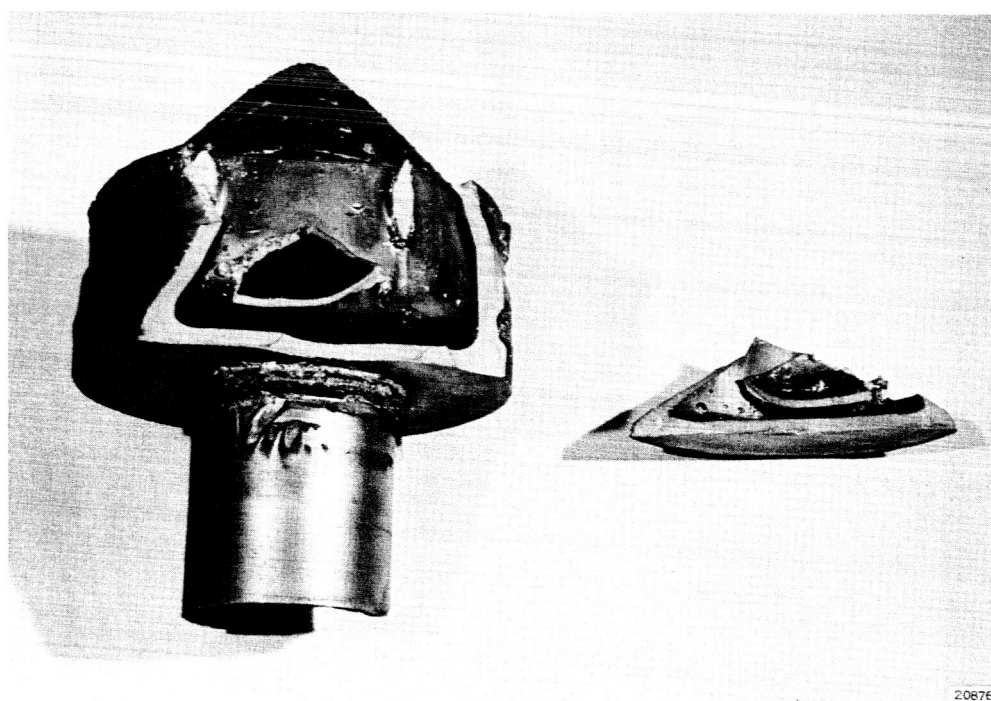


Figure A-25 - Valve Button Assembly, Vortex Chamber and
Plenum Chamber Liner

The tungsten button assembly failed in two places. The hot gas burned a hole through the cone-shaped leading edge and through the flat trailing face of the button assembly, as shown in Figures A-22 and A-23. It appears that the cone-shaped leading edge failed first with a long delay before the trailing edge failed. This delay was deduced from evidence of erosion around the button body bleed holes as shown in Figure A-24. This erosion pattern could only have been produced when there was simultaneous flow through the bleed hole and over the outside of the button. This particular flow condition would be most prominent when there was a hole in the button leading edge and when the trailing edge was intact. One possible solution to this problem is to use a button cap made of carbon phenolic in place of the tungsten cap.

The tungsten plenum chamber sleeve suffered from the same type of plastic distortion problems as did the vortex chamber. This particular distortion did not have any ill effect on the valve operation and need not be considered in the valve redesign.

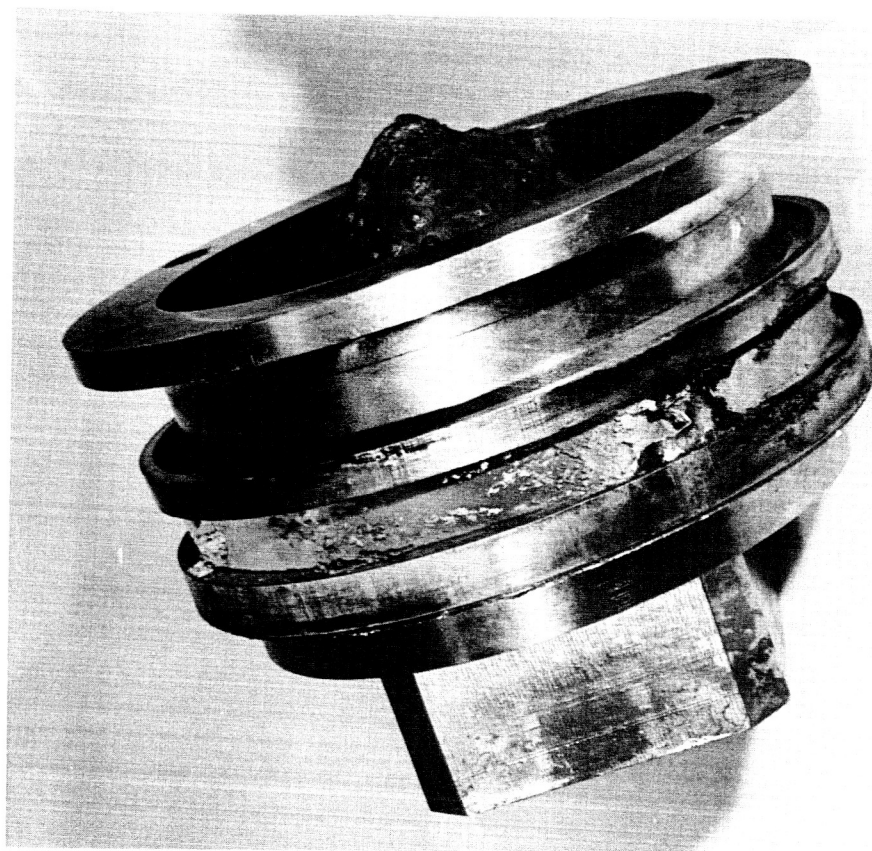
One major objective of the valve design tested was that the critical gas flow passages should remain free from undesirable aluminum oxide buildup. This objective was accomplished as is indicated by the open flow passages shown in Figures A-22, A-23, and A-25. The outlet portion of the valve remained in good general condition with only a small aluminum accumulation in the bottom of the valve plenum chamber, as shown in Figure A-26.

The vortex valve's control flow injectors were damaged extensively during the test. This damage was caused by the backflow of 5500°F gas through the injectors. The evidence of backflow can be seen by the aluminum deposits on the upstream end of the injectors and around the control port annulus, as shown in Figure A-27. This condition is not expected to occur during a test in which control flow is present.

Test Conclusions

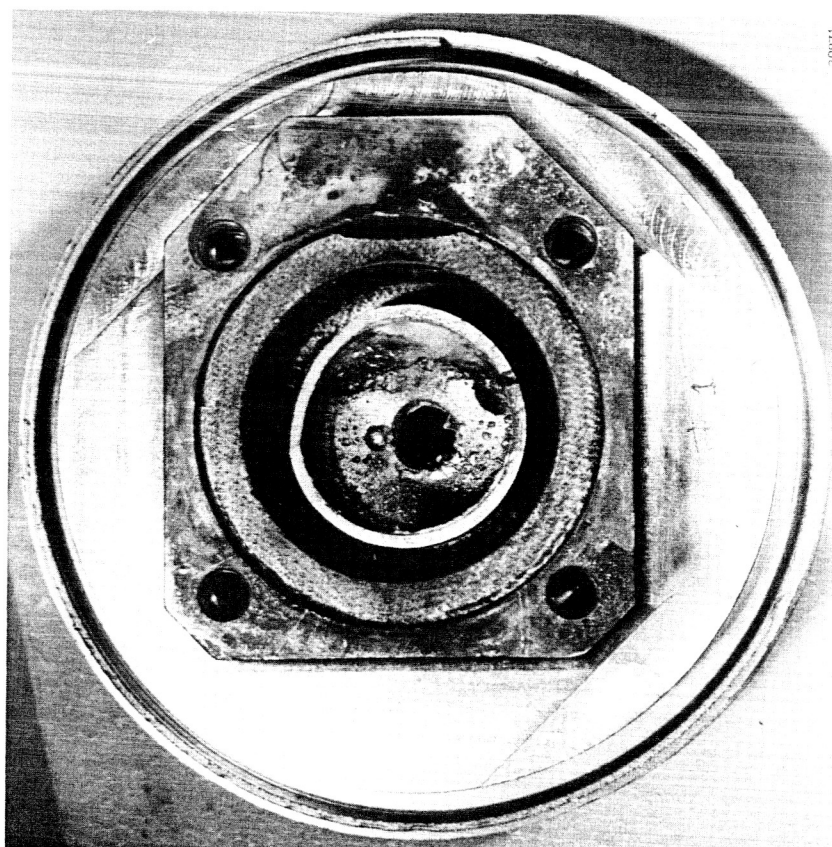
The following conclusions can be drawn after reviewing the hot and cold gas test results on the 5500°F SITVC Single Vortex Valve System.

1. Hot gas performance of the present system configuration can be predicted from cold gas test results with reasonable accuracy.



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Figure A-27 - Valve Body and Injector Holes



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Figure A-26 - Outlet End of Valve

2. The new vortex valve configuration has eliminated the detrimental aluminum oxide buildup about the button, the vortex chamber and the approach section to the vortex valve.
3. Design modifications of the vortex valve are required to prevent hot gas leakage about the P_o pressure sampling port.
4. The plastic condition of the tungsten parts and the lack of aluminum oxide deposit indicates that the system operating temperature was achieved early in the test and preignition time of the 2000°F SPGG can be reduced to coincide with the ignition of the 5500°F SPGG, if required.
5. A change in the orientation of the insulating fabric lay will provide better thermal and erosion resistant properties.
6. Coupling the 5500°F SPGG ignitor to the 2000°F SPGG output with a pressure switch will automatically abort the 5500°F SPGG in case the 2000°F SPGG fails to ignite or to come up to a predetermined pressure level.

APPENDIX B

**TEST PLAN FOR 5500°F SITVC SINGLE VALVE SYSTEM
HOT TEST NUMBER 3**

INTERDEPARTMENTAL

THE *Bendix* CORPORATION
RESEARCH LABORATORIES DIVISION

TO: W. D. Holt

DATE:

FROM: T. W. Keranen

COPIES:

SUBJECT: Test Plan for 5500°F SITVC
Single Valve System Hot Test Number 3

A. Blatter
R. L. Louisignau
G. L. McArthur
J. G. Rivard
J. H. Robertson
I. Scott
J. A. Sember
C. V. Simo
L. B. Taplin

Enclosed is the test plan for the 5500°F SITVC System Test Number 3. If there is any question regarding the enclosed, please contact the writer or Mr. W. D. Holt.

T. Keranen

APPENDIX B

TEST PLAN FOR 5500°F SITVC SINGLE VALVE SYSTEM HOT TEST NUMBER 3

The system to be tested is a single vortex valve 5500°F SITVC System with a 2000°F control stage. The major objective of the test is to demonstrate flow modulation of 5500°F solid propellant gas with a vortex valve and 2000°F solid propellant control gas. Also, this test provides the opportunity to verify the integrity of the valve design.

The test is to be conducted in two parts. The first part is a steady-state cold gas test of the system with N_2 used as supply and control gases. The second part of the test is a steady-state hot gas test of the system with the 5500°F SPGG used as the hot gas supply source and the 2000°F SPGG used as the hot gas control source. All of the testing will take place at CRETS.

Cold Gas Test

The purpose of the cold gas test is to determine the steady-state performance characteristics of the single vortex valve SITVC System and to verify the intended performance of the system's various components (control valve, vortex valve, sequencer, etc.) prior to the hot gas test. All of the cold gas test data will be converted and published as equivalent hot gas performance. The cold gas test will be conducted in three parts as described below.

Control Valve Performance

The control valve performance will be determined from data recorded from a test setup as shown in Figure B-1. The test will be run with P_c varying from 0 to 1500 psig. The recorded data will be used to obtain valve flow rate, \dot{w} , versus control pressure, P_c .

Vortex Valve Performance

The vortex valve cold gas performance test will be run twice with two different instrumentation systems and test procedures. The first cold gas test arrangement is shown in Figure B-2. A Sanborn recorder will be used for this setup. All of the pressure, temperature, and flow meter frequency

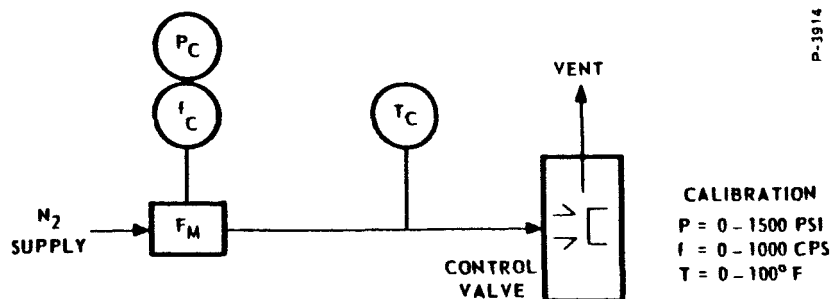


Figure B -1 - Test Schematic for Cold Gas Test of Control Valve

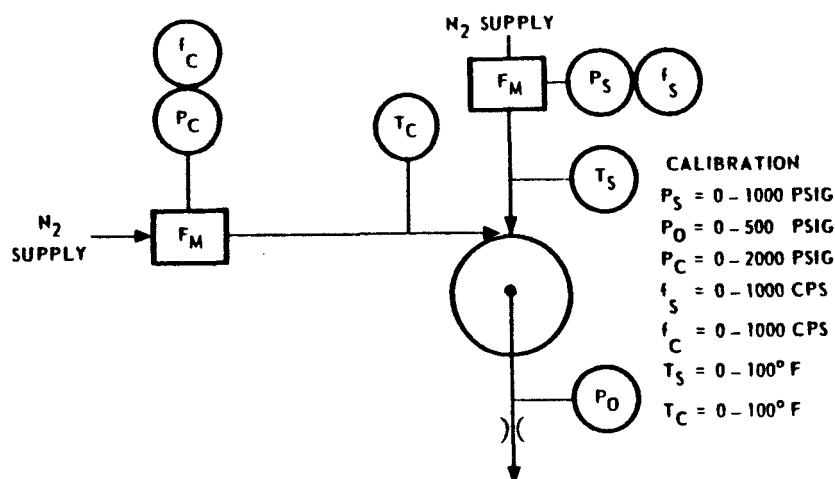


Figure B-2 - Test Schematic for Cold Gas Test of Vortex Valve

data will be recorded simultaneously, with no switching circuits or manual recording in the test setup. This portion of the vortex valve cold gas performance test will be run three times with P_s regulated at 950, 700 and 500 psig while P_c is modulated through ranges required for valve turndown. The data recorded will be used to obtain the following vortex valve performance characteristics:

$$\dot{\omega}_o \text{ versus } P_o$$

$$\dot{\omega}_c \text{ versus } P_s$$

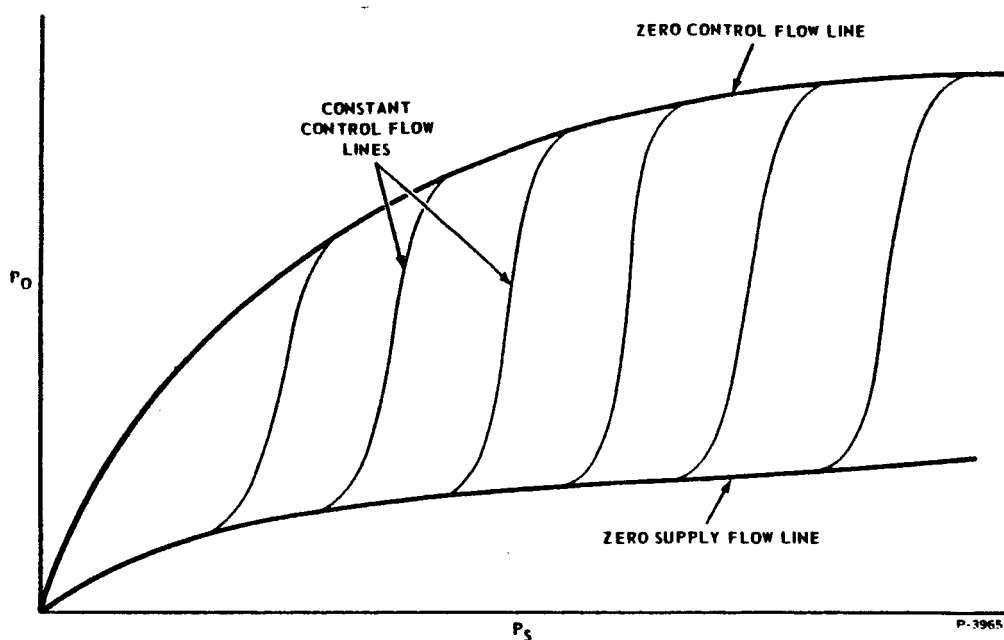


Figure B-3 - Vortex Valve Intended Cold Gas Performance Characteristics as Obtained from an X - Y Plotter

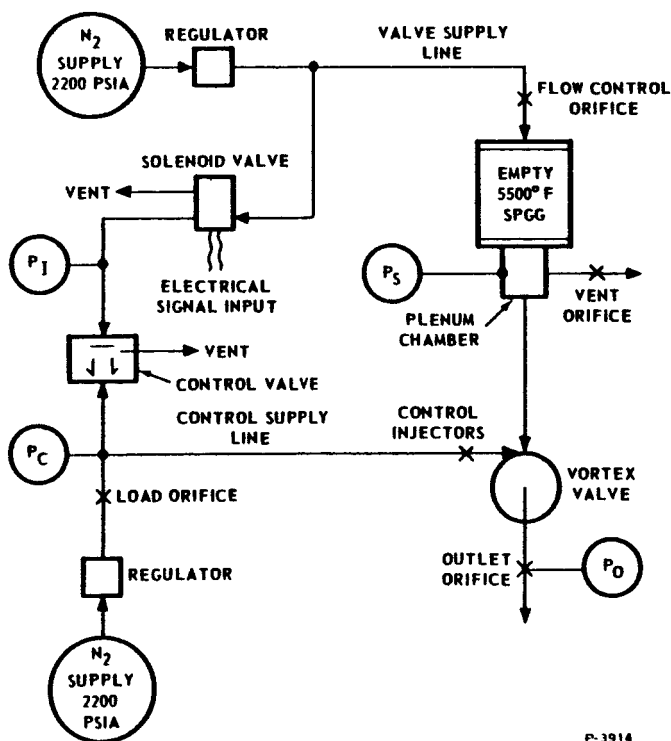


Figure B-4 - Test Schematic for Cold Gas Test of 5500°F SITVC System - Single Vortex Valve

$$\dot{\omega}_o / \dot{\omega}_{o \max} \text{ versus } P_c / P_s$$

$$\dot{\omega}_c / \dot{\omega}_{o \max} \text{ versus } P_c / P_s$$

The second portion of the vortex valve cold gas performance test will be run utilizing an x - y plotter. The plotters' y scale will record P_o and the x scale will record P_s . The test will be conducted in a manner to obtain the following data on one plot.

- (1) Plot of P_o versus P_s with no supply flow (supply blocked) and the control pressure varied from 0 to 1300 psig.
- (2) Plot of P_o versus P_s with no control flow (control blocked) and the supply pressure varied from 0 to 1000 psig.
- (3) Plot of P_o versus P_s with P_c held constant and P_s varied from 0 to 1000 psig. This procedure will be run for constant values of P_c from 400 to 1300 psig in 50 psig increments.

The intended performance characteristics for this test are shown in Figure B-3.

Single Vortex Valve SITVC System Performance

The single vortex valve SITVC System performance characteristics will be determined from data recorded from a test setup as shown in Figure B-4.

The cold gas test will be set up and run in a manner so as to approximate the hot gas test of the same system. The cold gas supplied to the SPGG vent and vortex valve combination will be at a constant flow rate as controlled by the orifice upstream of the empty SPGG. The value of P_s , when the vortex valve is fully turned down, will be 950 psig. The vortex valve control pressure, P_c , will be modulated by the control valve, which in turn receives an input signal from the solenoid valve. The solenoid valve will be actuated by the sequencer that is to be used in the hot gas test.

The data recorded in this portion of the cold test will indicate the compatibility of the system's many components and suggest any necessary system changes required prior to the hot test.

Hot Gas Test

The test schematic for the hot gas test is shown in Figure B-5. This test will provide information on the ability of the vortex valve to modulate 5500°F gas.

The 5500°F SPGG will be used to supply the vortex valve and the 2000°F SPGG will provide the control gas. The ignition of the SPGGs, the modulation of the control gas by the solenoid valve, and the starting of the recorders, cameras, and timers will be controlled by a sequencer. A pressure switch with its sensing point at the 2000°F SPGG will be used

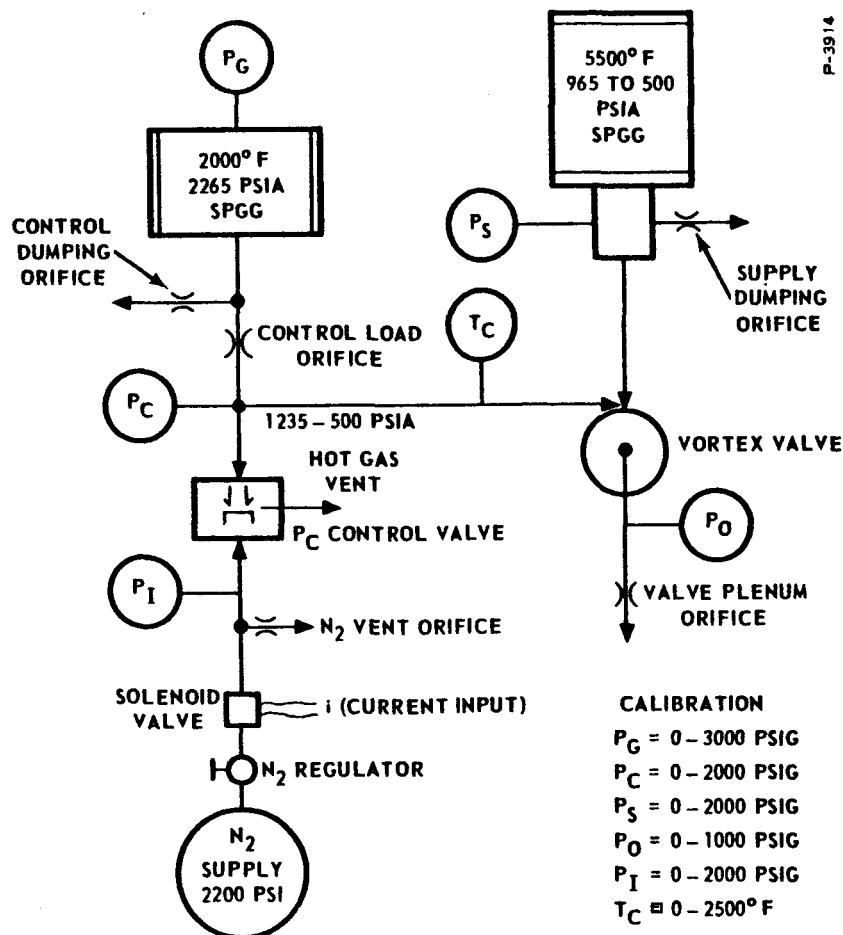


Figure B-5 - Test Schematic for Cold Gas Test of 5500°F SITVC System with Single Vortex Valve

to abort the 5500°F SPGG ignition in case the 2000°F SPGG fails to fire. The time pattern of the sequencer will be as follows:

<u>Time</u>	<u>Function</u>
0 sec	Start 3 low speed cameras, high speed camera, solenoid valve.
2 sec	Ignite 2000°F SPGG.
4 sec	Ignite 5500°F SPGG, turn off 2000°F ignitor.
6 sec	Close solenoid valve and turn off 5500°F SPGG ignitor.
9 sec	Open solenoid valve.
11 sec	Close solenoid valve.
14 sec	Open solenoid valve.
16 sec	Close solenoid valve.
19 sec	Open solenoid valve.
21 sec	Close solenoid valve.
24 sec	Open solenoid valve.
26 sec	Close solenoid valve.
28 sec	Open solenoid valve.
30 sec	Close solenoid valve.
58 sec	Turn off recorder, high speed camera, 1 low speed camera, number 4 and sequencer.

Prior to the hot gas test, the complete system (except the SPGG ignitors) will be checked out on a simulated hot gas test. The firing procedure for the hot gas test is described in the accompanying engineering specification.

Photographic Coverage of Hot Gas Test

The hot gas test photographic coverage will consist of movie and still pictures. 35 mm color slides, 8-1/2 x 11 black and white, and 8-1/2 x 11 color still pictures will be taken as verbally specified by the responsible engineer. The black and white pictures will be taken in the following five general steps:

- (1) Prefire unassembled hardware - 35 mm color slides and 8-1/2 x 11 black and white pictures to be taken at the laboratories.
- (2) Prefire test setup - 35 mm color slides and 8-1/2 x 11 black and white pictures of the hardware and instrumentation assembled on test fixture ready to test.
- (3) During firing - 35 mm color slides and 8-1/2 x 11 color pictures of test during operation. The camera will be automatically controlled to take one picture every 1 second for 58 seconds.
- (4) Post firing test setup - 35 mm color slides 8-1/2 x 11 black and white pictures of the hardware and instrumentation assembled on the fixture after test.
- (5) Post firing unassembled hardware - 35 mm color slides and 8-1/2 x 11 black and white pictures of hardware during disassembly.

After proof editing by the responsible engineer, 5 copies of the 8-1/2 x 11 pictures and 2 copies of the color slides will be made.

The movie coverage of the test will be provided by three low speed (64 fps) 16 mm cameras and one high speed (240 fps) camera. These cameras will be controlled automatically and will be located as shown in Figure B-6. Movies will also be taken of the test setup before and after the firing using approximately 50 feet of film each time. After the films have been edited by the responsible engineer, 2 copies of the movies will be made. The assigned photographer will report to the responsible engineer the movie camera settings used during the test.

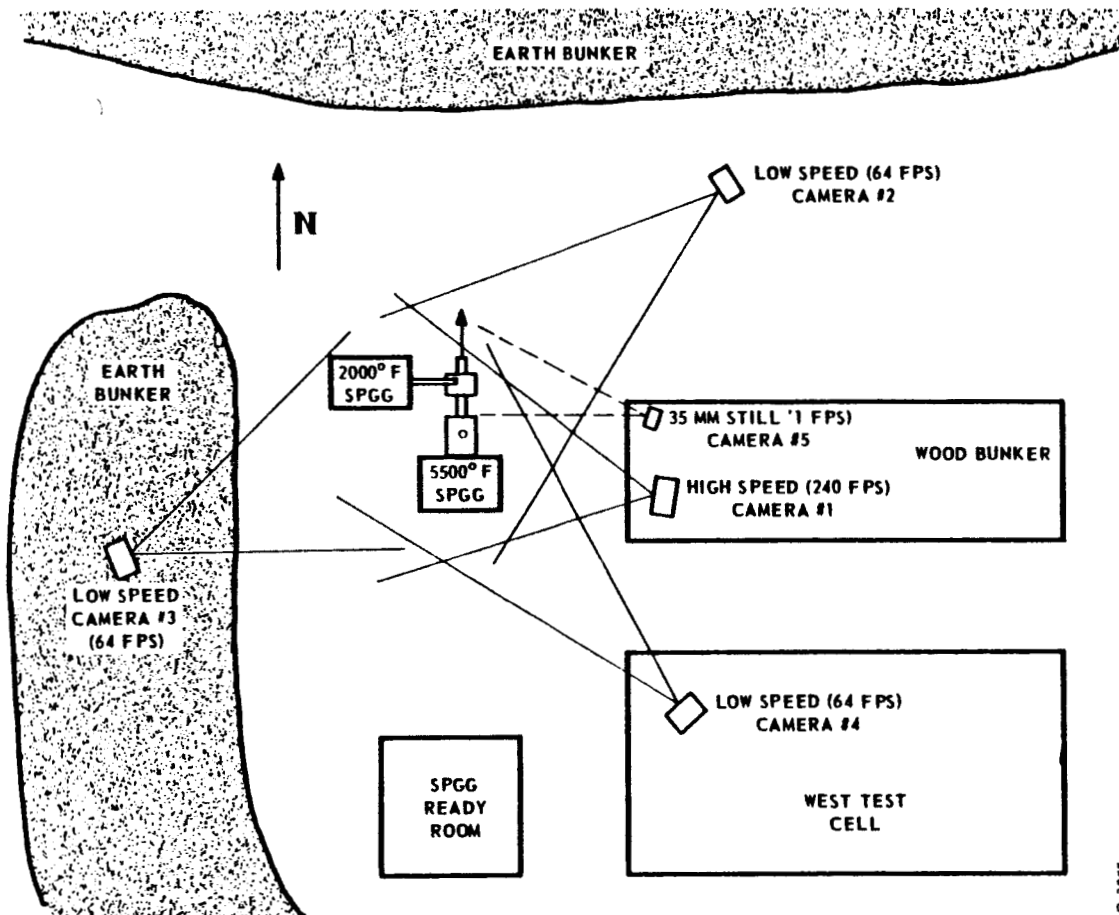


Figure B-6 - Camera Locations

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TITLE												
5500°F SITVC System Hot Gas Test Procedure												
DATE												
28 April 1966												
<p>Test No. _____ Date _____</p> <p>1. General Rules</p> <p>1.1 There shall be no more than four people in the console room during prefiring checkout.</p> <p>1.2 After a loaded SPGG has been placed in the test cell, only the following personnel are authorized to enter the cell.</p> <p style="margin-left: 40px;">(a) Test site safety engineer.</p> <p style="margin-left: 40px;">(b) Assigned test technicians.</p> <p style="margin-left: 40px;">(c) Responsible engineer.</p> <p>1.3 The test cell shall be off limits to all personnel after countdown Item 3.18, except for the following.</p> <p style="margin-left: 40px;">(a) Assigned test technician.</p> <p style="margin-left: 40px;">(b) Responsible engineer.</p> <p>2. 2000°F SPGG and Pilot Stage System</p> <p>2.1 _____ All items pertaining to loading of the 2000°F SPGG accomplished as described in Olin test procedure S.O.P. 4549000 and breech assembly print Bendix 2159667.</p> <p>2.2 _____ Couple the 2000°F SPGG to the pilot stage system and torque mounting screws as required.</p> <p>2.3 _____ Install outlet plugs.</p> <p>2.4 _____ Install new burst diaphragm.</p>												
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2830				11272		
ENGINEERING SPECIFICATION						
TITLE 5500°F SITVC System Hot Gas Test Procedure					DATE 28 April 1966	
Test No. _____ Date_____						
3. 5500°F SPGG and SITVC Supply System						
3.1____All items pertaining to loading accomplished as described in Hercules Powder Test Procedure UOP-066-18-2 for the 5500° F SPGG.						
3.2____The 5500°F SPGG mounted to the 5500°F SITVC System per Bendix and the mounting screws torqued as required.						
3.3____Install outlet plugs.						
3.4____Install new burst diaphragm.						
3.5____Calibrate pressure pickups and thermocouples using a 4 point calibration. (Leave calibration on strip chart.)						
3.6____Leak check system mounting surfaces by pressurizing systems to 200 psi.						
3.7____Remove N ₂ supply line and install applicable plug.						
3.8____Make complete system checkout with simulated hot test.						
3.9____Load cameras. Make final camera adjustments and record all settings. Camera No. 1 No. 2 No. 3 No. 4 No. 5 Lens setting Camera speed Film ASA No.						
3.10____Zero timer.						
3.11____Install firing cables in shorting plug in console. 2000°F SPGG_____ 5500°F SPGG_____						
3.12____Place firing switch in "OFF" position.						
3.13____Set recorder speed and timing lines. (Speed____ Timing____)						
3.14____Set programmer (One complete cycle in ____seconds)						
PREPARED BY		CHECKED BY		APPROVED BY		
REVISIONS						

PROJECT NO. 2830	THE BENDIX CORPORATION RESEARCH LABORATORIES DIVISION SOUTHFIELD, MICHIGAN	CODE IDENT. 11272	SPECIFICATION NO. 	REV.
ENGINEERING SPECIFICATION				
TITLE 5500°F SITVC System Hot Gas Test Procedure			DATE 28 April 1966	
<p>Test No. _____ Date _____</p> <p>3.15 _____ Notify test site engineer of pending firing.</p> <p>3.16 _____ Received permission to fire. (Authorized by _____)</p> <p>3.17 _____ Remove outlet plugs from test system.</p> <p>3.18 _____ Check ignitor cables for continuity at ignitor connector.</p> <p>3.19 _____ Install ignitor and ignitor cable.</p> <p>3.20 _____ Open N₂ control source.</p> <p>3.21 _____ Remove firing cables from shorting plug and place in firing position on test panel.</p> <p>3.22 _____ Turn on D.C. and A.C. power to console.</p> <p>3.23 _____ Start sequencer.</p> <p>3.24 _____ After completion of test the responsible engineer and assigned technician investigate the test site and notify the other personnel when the test site is safe for review.</p> <p>3.25 _____ Assign test number and date to strip charts.</p> <p>Remarks: _____</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>Test Engineer _____</p> <p>Responsible Engineer _____</p>				
PREPARED BY		CHECKED BY		APPROVED BY
REVISIONS				